Summer 2019 IceBridge Arctic Flight Plans
25 June 2019 Draft

compiled by

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Introduction to Flight Plans

This document is a translation of the NASA Operation IceBridge (OIB) scientific objectives articulated in the Level 1 OIB Science Requirements, at the June IceBridge Arctic planning meeting held at the University of California at Irvine, through official science team telecons and through e-mail communication and iterations into a series of operationally realistic flight plans, intended to be flown aboard NASA's G-V aircraft roughly from mid-August to mid-September 2019. The material is shown on the following pages in the distilled form of a map and brief text description of each science flight.

For each planned mission, we give a map and brief text description for the mission. The missions are planned to be flown from Thule and Kangerlussuaq, Greenland. A careful reader may notice that some of the mission maps in the main part of the document highlight flightlines in green, yellow, and red colors, while other only show the black lines. The colors are a refinement added to the flight plans at a late stage of design which help the field team navigate the aircraft properly to achieve specific science goals. The colors represent the degree of “straightness” of each flight segment, where straight segments are steered using an automated technique and curved sections using a specialized manual method. Not all of the flight plans shown here have necessarily reached that mature stage of design.

In fact, as a general rule the flight plans depicted here are all at varying stages of completeness. For each mission we note “Remaining Design Issues” to be resolved, if any exist. In most cases these are minor. ICESat-2, CryoSat-2 and Sentinel 3a underflights are a major exception, since these have to be re-planned for each potential flight day (for sea ice) or within a window of several potential flight days (for land ice). Sea ice camp/site overflights are also an exception, since these move with the motion of the ice, unless they are situated on shore-fast ice.

Note that this document shows 20 planned land ice and 4 planned sea ice missions (one of which is a placeholder for up to three), which is more than we expect to fly this year. The extra flight plans give us operational flexibility to fly as much as possible, and scientifically productive, while we are in the field. The entire suite of 24 flight plans is depicted in the introductory material following this text. Each flight has a priority assigned to it by the OIB science team, either high, medium or low, and these are listed below with each mission.

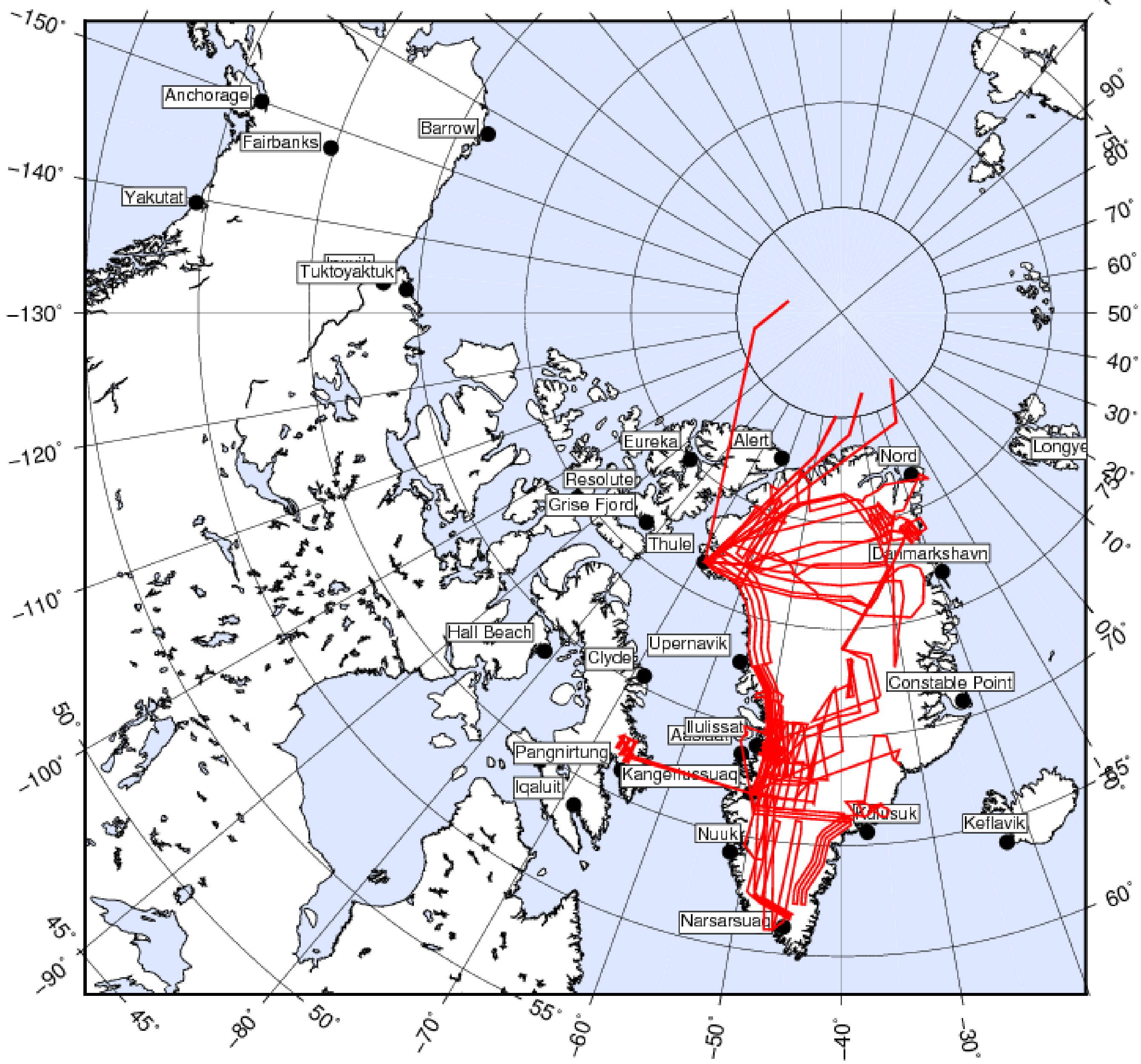
Additional notes on flight prioritizations

Due to the recent launch of ICESat-2 and OIB’s role in performing the “bridge” function to the new spacecraft, flight prioritizations for 2019 contain more nuance than in prior years. Here we spell out the additional considerations relating to flight priorities.

For sea ice, we aspire to fly four missions. Of these, we plan for three of them to be ICESat-2 low-latency “racetrack” flights, and one to be a Lagrangian-displaced version of one of the spring 2019 racetrack flights

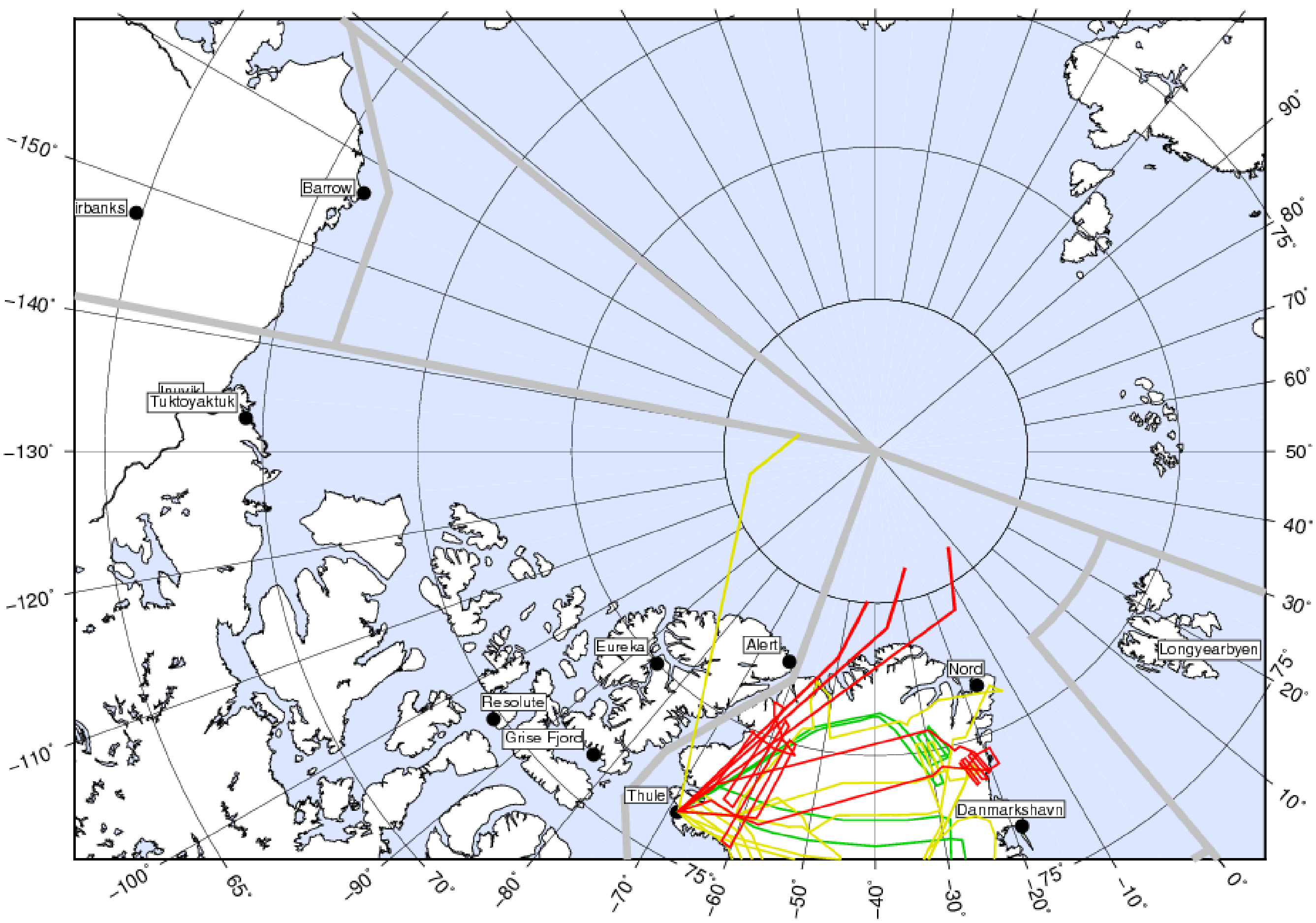
For land ice, for the most part, the priorities listed for each mission in this document tell the full story. The exception is that we intend to replace a few lines in some land ice missions with low-latency (preferably a few hours) ICESat-2 tracks. These are preferred to be in southwest Greenland where we have a reasonable probability of observing melt.

2019 Summer IceBridge Missions



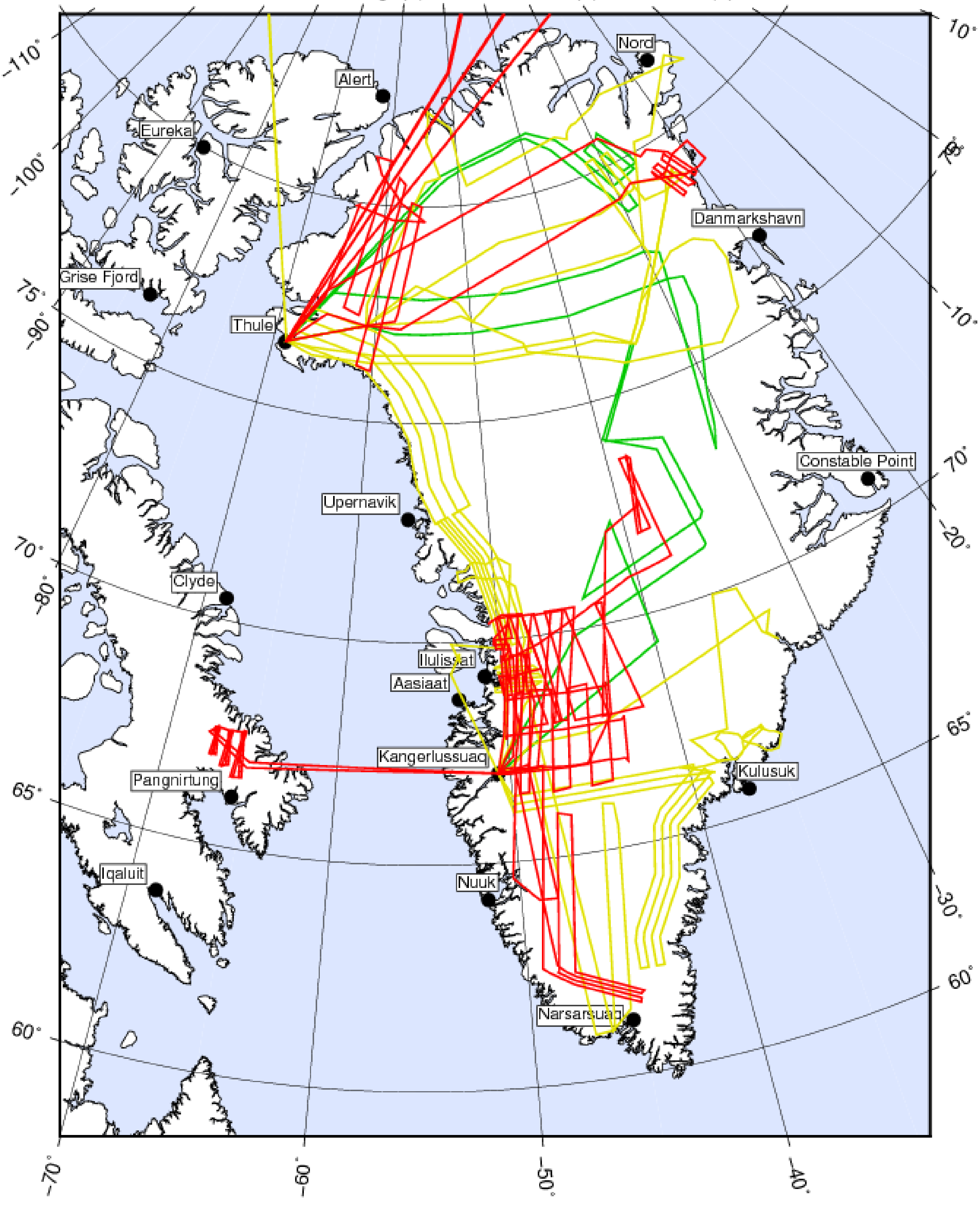
Prioritized Summer 2019 OIB Sea Ice Missions

Red:High(3) Yellow:Medium(1)



Prioritized Summer 2019 OIB Land Ice Missions

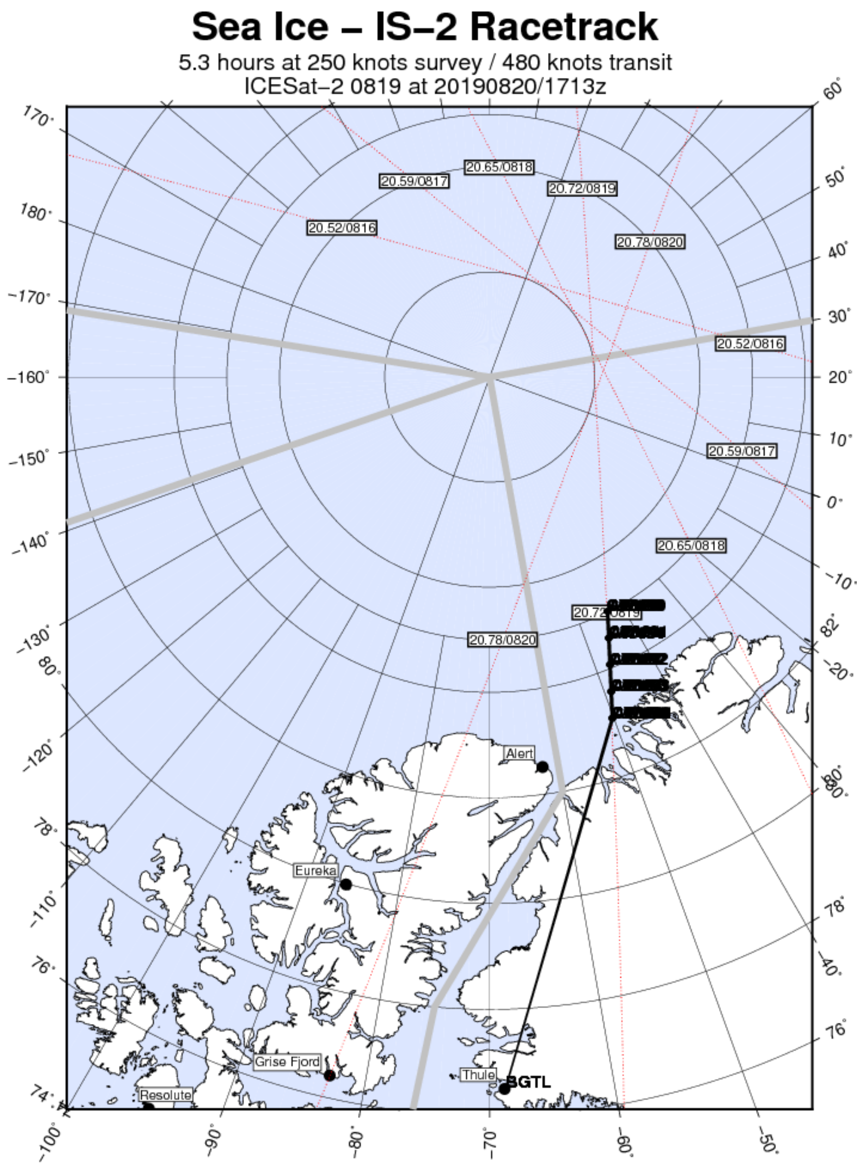
Thick Red:High(8) Yellow:Medium(9) Green:Low(3)



Sea Ice – IS-2 Racetrack / Thule

This “racetrack” flight design is intended to maximize the chance of coincident ATM and ICESat-2 coverage over the same swath of sea ice, in the presence of sea ice drift and potential IS-2 pointing errors. The design concept is the same as the similar spring 2019 “Sea Ice – IS-2 Arctic Ocean Racetrack” flights, but displaced to the east according to the late August-early September positions of the IS-2 ground tracks. We fly this mission at 3500’ MSL, to maximize ATM scan swath but also remain within the range window of the snow radar. See Appendix D for more details on the design of these flights.

Flight Priority: high x 3
IceSat-2 Tracks: TBD
Last Flown: new flight
Remaining Design Issues: see Appendix D



Sea Ice – Lagrangian Racetrack / Thule

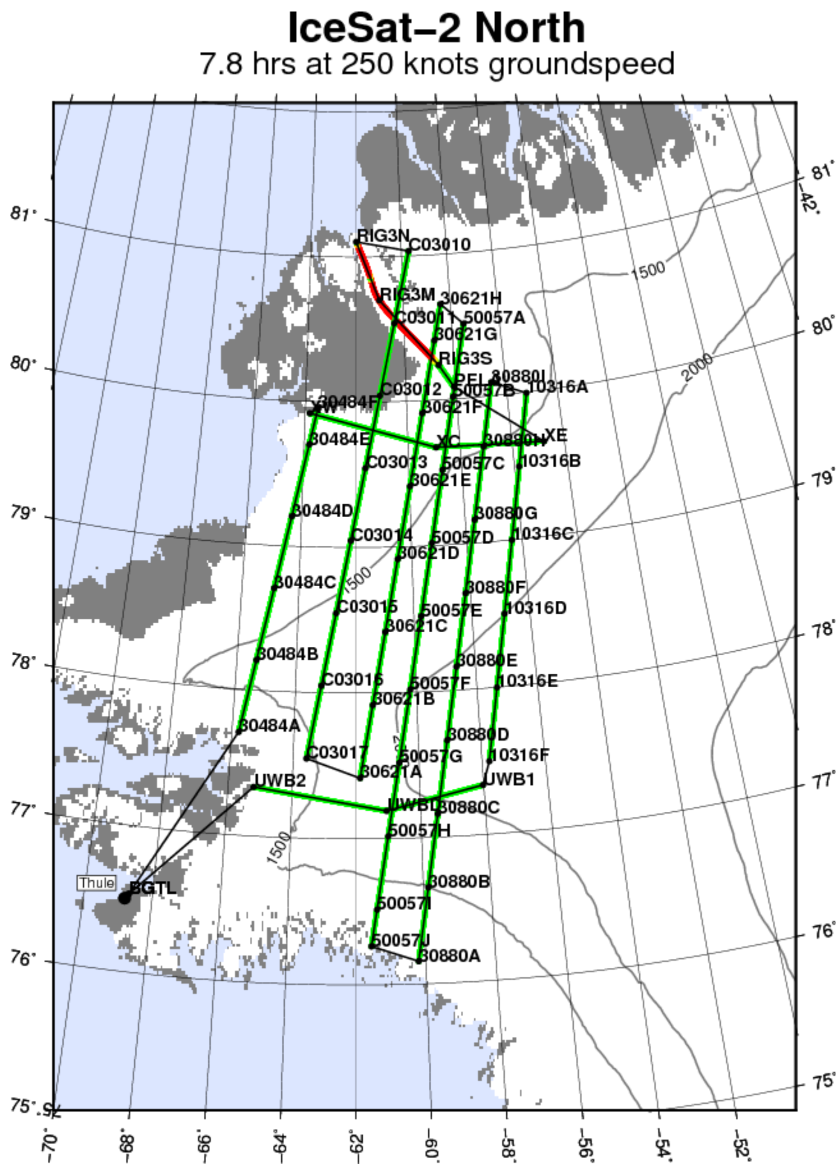
This flight is intended to fly, in generalized terms, the “same” racetrack-shaped swath of sea ice flown on 12 April 2019, as that sea ice has drifted in the intervening months. The drifted flight path will be provided on a regular basis by members of the OIB science team.

Flight Priority: medium
IceSat-2 Tracks: none (propagated from spring 2019)
Last Flown: new flight
Remaining Design Issues: Lagrangian drift of the flight path will be periodically updated

Land Ice – IceSat-2 North / Thule

This mission is designed to overfly planned IceSat-2 ground tracks over a wide range of ice regimes near Thule. We center some of the flightlines on each of three beam pairs (left, nadir and right) in turn, sampling at least one of each beam pair during this mission. The east-west crossing line is designed to capture as many ascending/descending crossovers as possible. We also fly a particular flowline of Petermann Glacier which has been sampled intermittently during the ATM and OIB eras, overflying two GCNet sites in the process. For 2018 we modify the return leg to Thule to overfly a segment of an Ultra-wideband radiometer (UWBRAD) flight line, at the request of Ken Jezek.

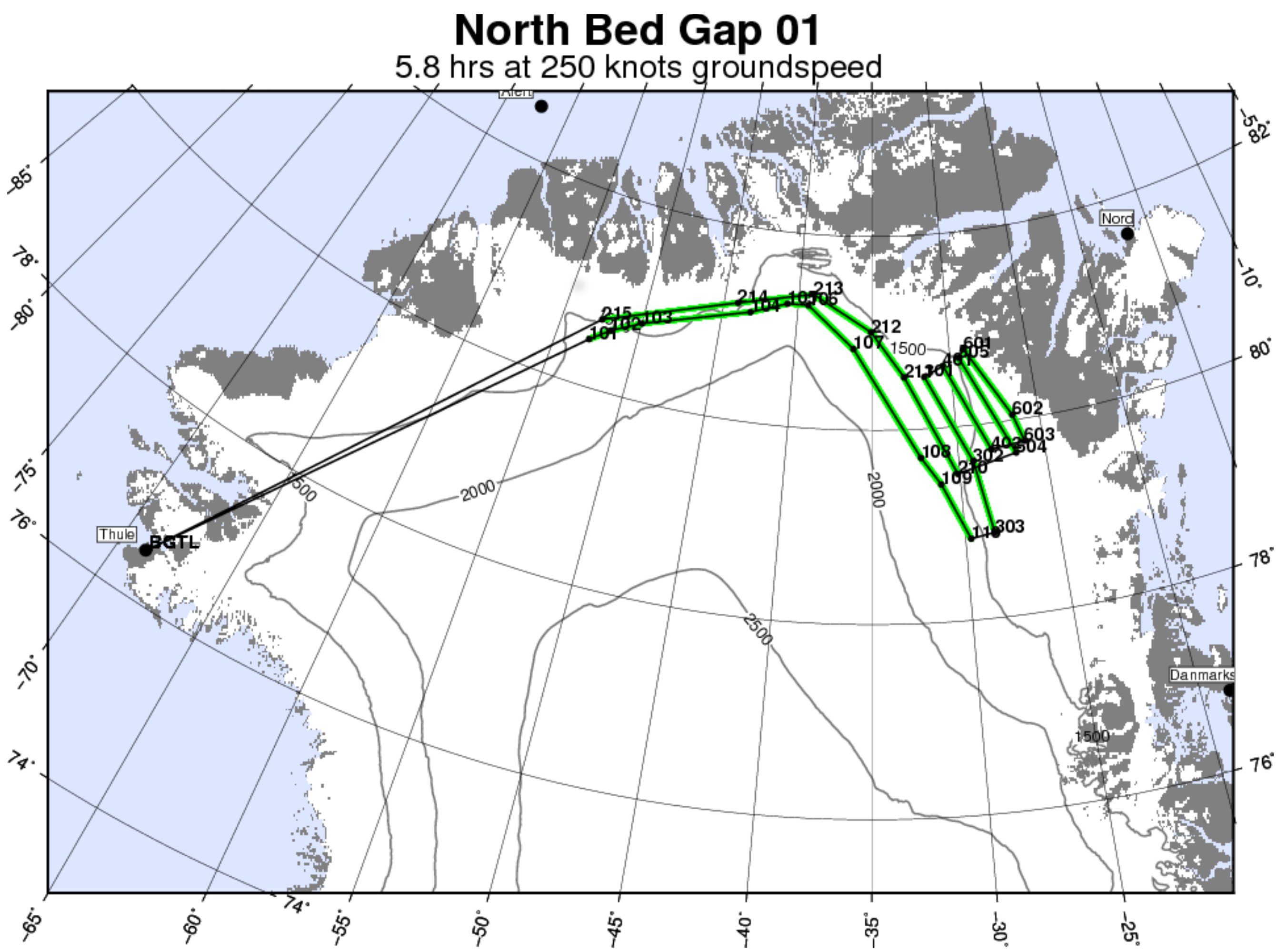
Flight Priority: high
IceSat-2 Track: 0484,1246,0621,0057,0880,0316
Last Flown: 2019
Remaining Design Issues: none



Land Ice – North Bed Gap 01 / Thule

This new mission for 2019 addresses gaps in bed measurements identified by Mathieu Morlighem on the northern and northeastern flank of the ice sheet.

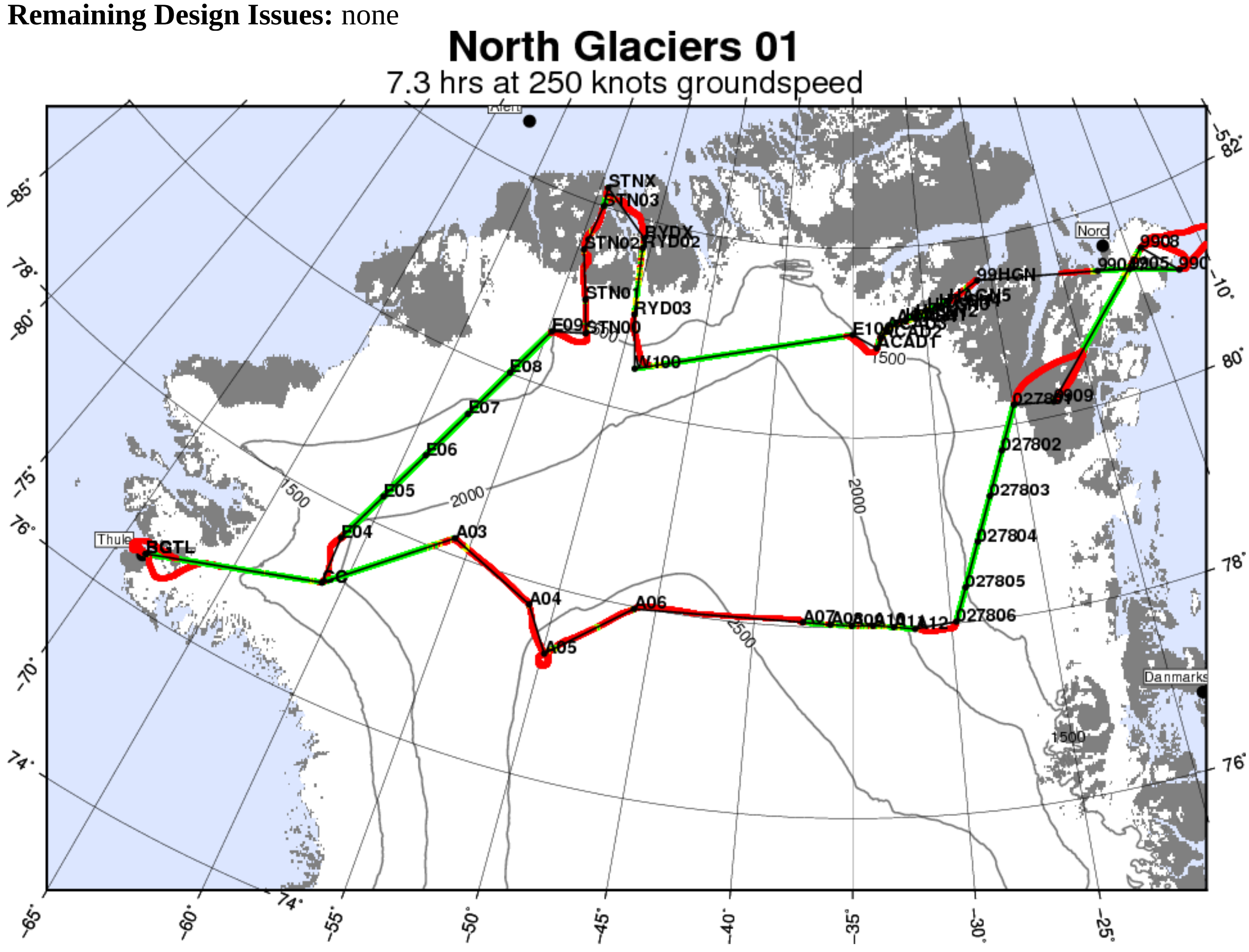
Flight Priority: low
ICESat Track: none
Last Flown: 2019
Remaining Design Issues: none



Land Ice – North Glaciers 01 / Thule

This mission is designed to resurvey historical ATM longitudinal surveys of several glaciers in northern Greenland, including Steensby, Ryder, and Hagen Glaciers. It also re-occupies ATM lines on the Flade Ice Cap, near Station Nord, and returns to Thule along the British North Greenland Expedition traverse line, which was also flown by ATM in 2002.

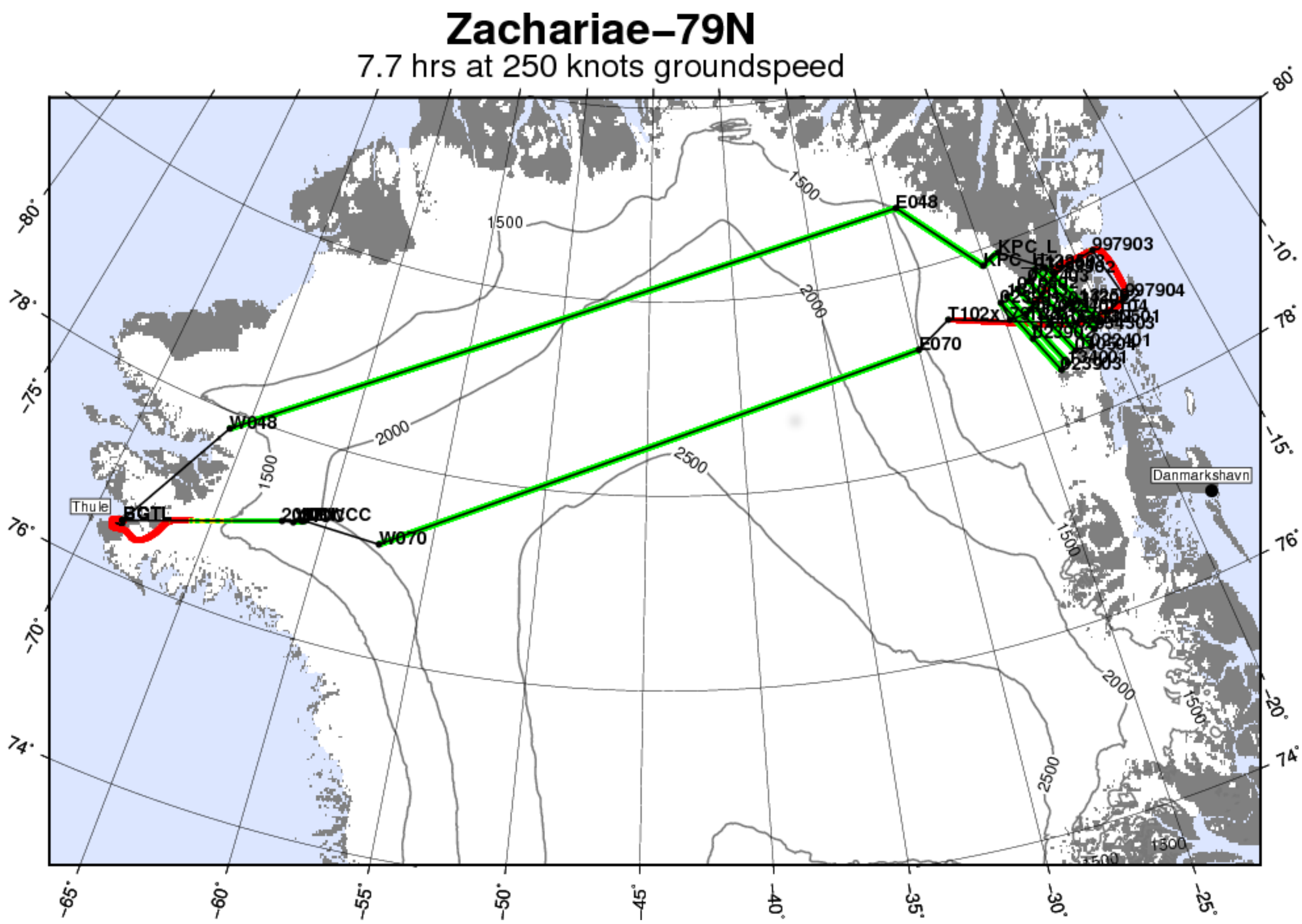
Flight Priority: medium
ICESat Track: 0278
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Zachariae-79N / Thule

This mission reoccupies the centerlines of the Zacharaie and 79N glaciers, plus flies a grid of six ascending IceSat-1 tracks similar to one originally flown by OIB in 2012, but moved upstream by two IceSat-1 groundtracks to account for the breakup of the lower ice shelf. It also overflies a pair of PROMICE sites immediately north of 79N Glacier. We transit to the northeast region along a historical ATM line dating back to 1994. For 2019 we replace the east-west transit lines with new master grid lines, selected to fill gaps in knowledge of bedrock.

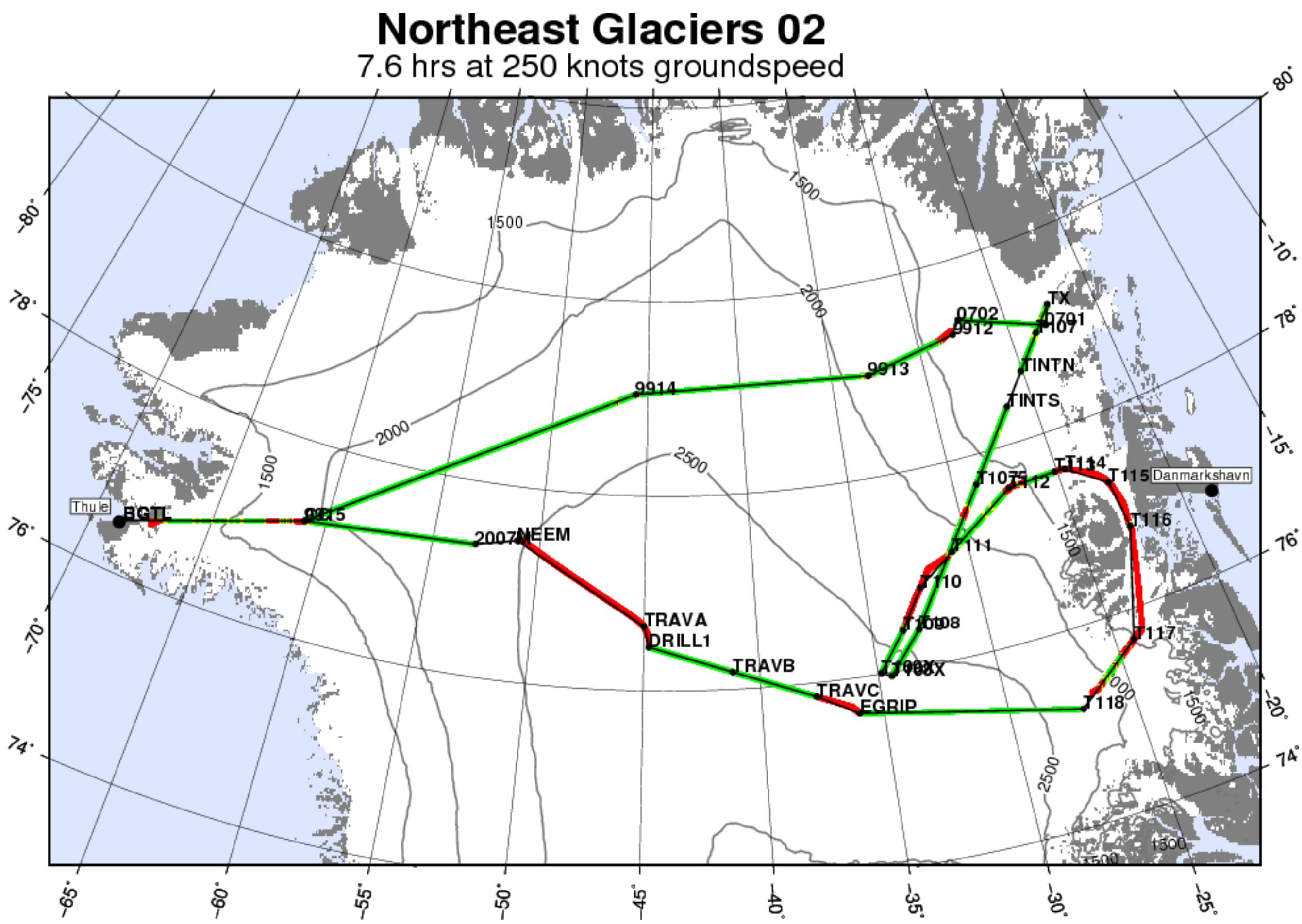
Flight Priority: high
ICESat Track: 0105,0224,0239,0343,1325,1340
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Northeast Glaciers 02 / Thule

This mission reoccupies the centerlines of the Storstrommen and L Bistrup glaciers, as well as an extension of the Northeast Greenland Ice Stream from Zachariae and 79N Glaciers into the main ice sheet. This southward extension along the ice stream reflies the 2 May 2007 lines, and extends them 60 km farther up the trunk of the ice stream. We transit to and from the northeast region along a historical ATM line dating back to 1994, and along a Danish ground traverse route connecting NEEM and EGRIP core sites. Measurements collected during the ground traverse may permit enhanced interpretation of shallow radar data from OIB.

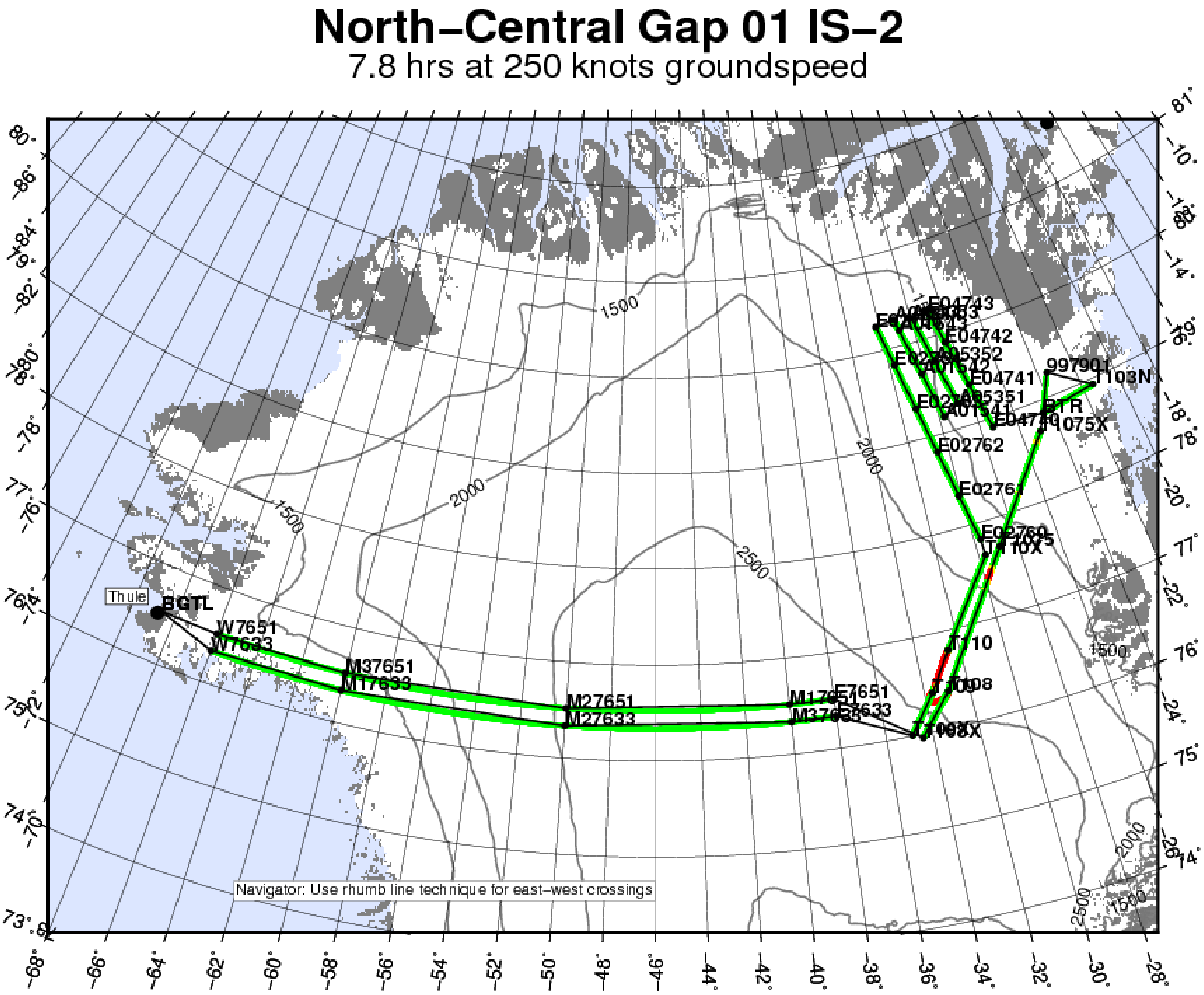
Flight Priority: medium
ICESat Track: none
Last Flown: 2019
Remaining Design Issues: none



Land Ice – North Central Gap 01 IS-2 / Thule

This mission, along with the North Central Gap 02 and 03 missions, are primarily designed to fill a gap in altimetry and radar coverage of the north-central portion of the ice sheet. The flight was modified for 2015, where we removed the centerlines of Zachariae and Storstrommen Glaciers (covered in other flights), and added reflights of four 2010 grid lines on the upper Zachariae/79N catchment, extended upstream centerlines of both glaciers, and a flowline passing through the TUNU core site. For 2019 we modify the east-west crossings to target low-latency IS-2 crossover latitudes, we replace the 2010 grid lines with low-latency ICESat-2 ground tracks, and we also fly parallel extensions of previous lines on the upper NEGIS. These extension lines are new.

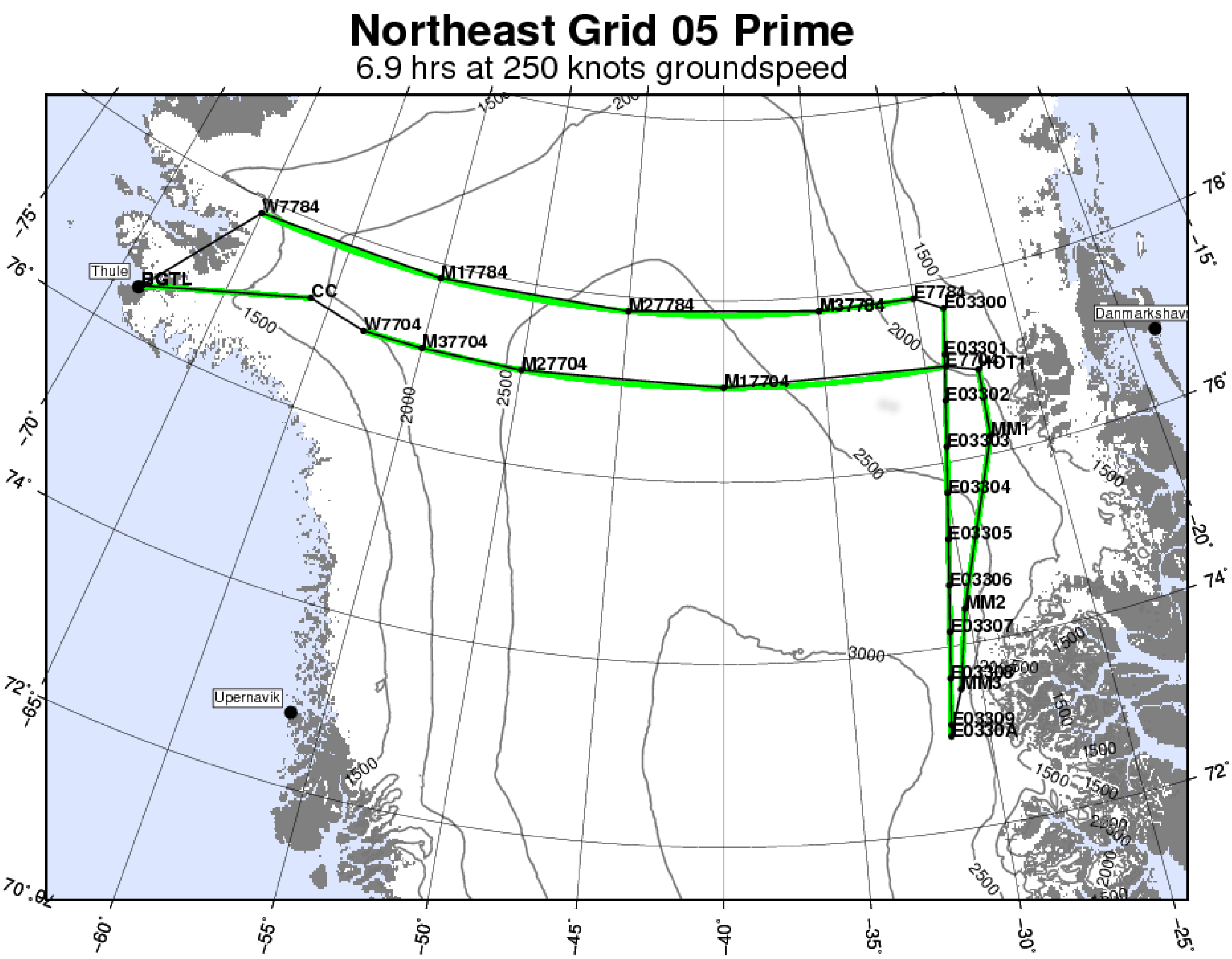
Flight Priority: medium
ICESat-2 Tracks: E0276,A0154,A0535,E0474
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Northeast Grid 05 Prime / Thule

This is a new mission, one of a suite of six flights intended to thoroughly sample the bedrock topography of northeast Greenland along a series of nearly coast-parallel ICESat lines. For 2019 we completely redesign this flight, although the original purpose remains the same. We change the east-west transit lines to follow the latitudes of low-latency ICESat-2 crossovers, and we fly a low-latency IS-2 ground track in the east, which also covers a "hot-spot" in the bed uncertainty. We fly a second roughly north-south line in the east targeted at multiple such hot-spots.

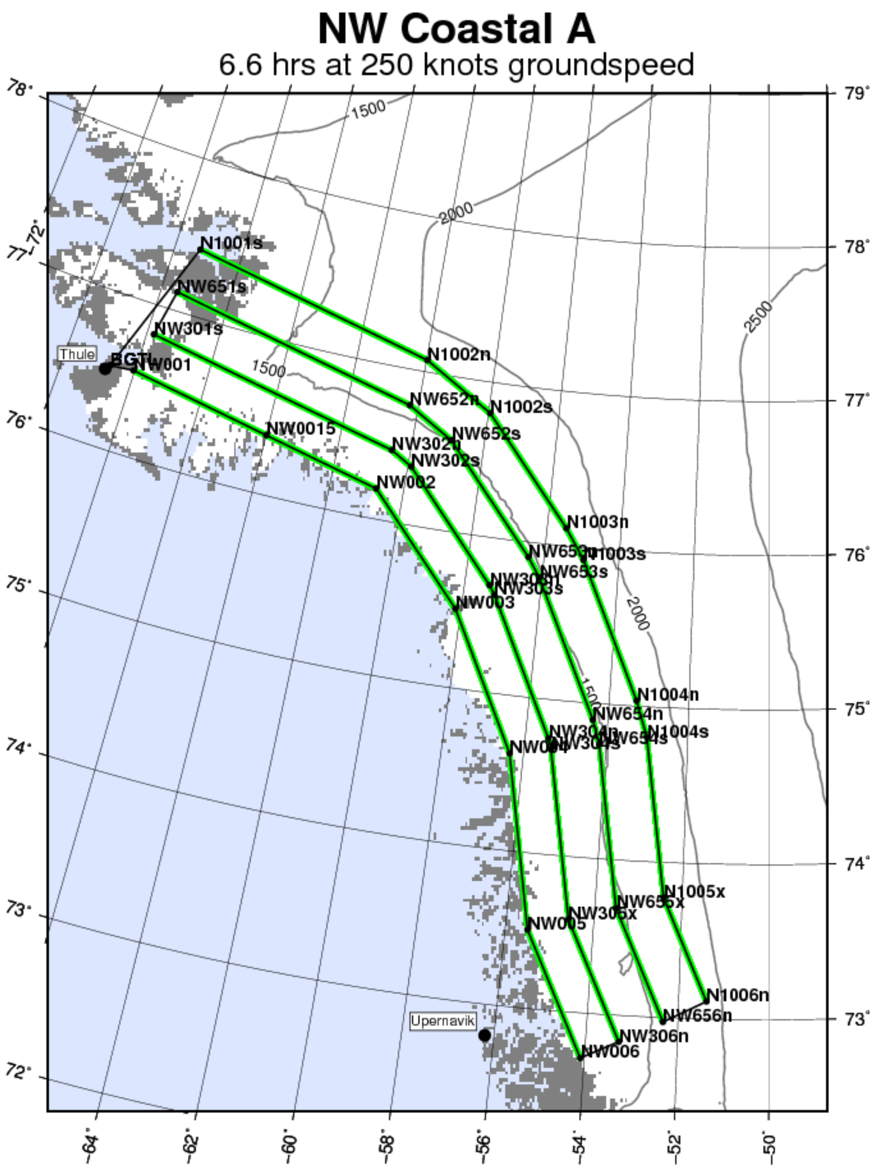
Flight Priority: low
ICESat-2 Track: E0330
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Northwest Coastal A / Thule

This is a new mission, created from the 2010-2012 “Northwest Coastal” suite of missions by sampling individual coast-parallel lines from those flights to form a grid spaced at 30-35 km from the coast to near the 2000m contour line.

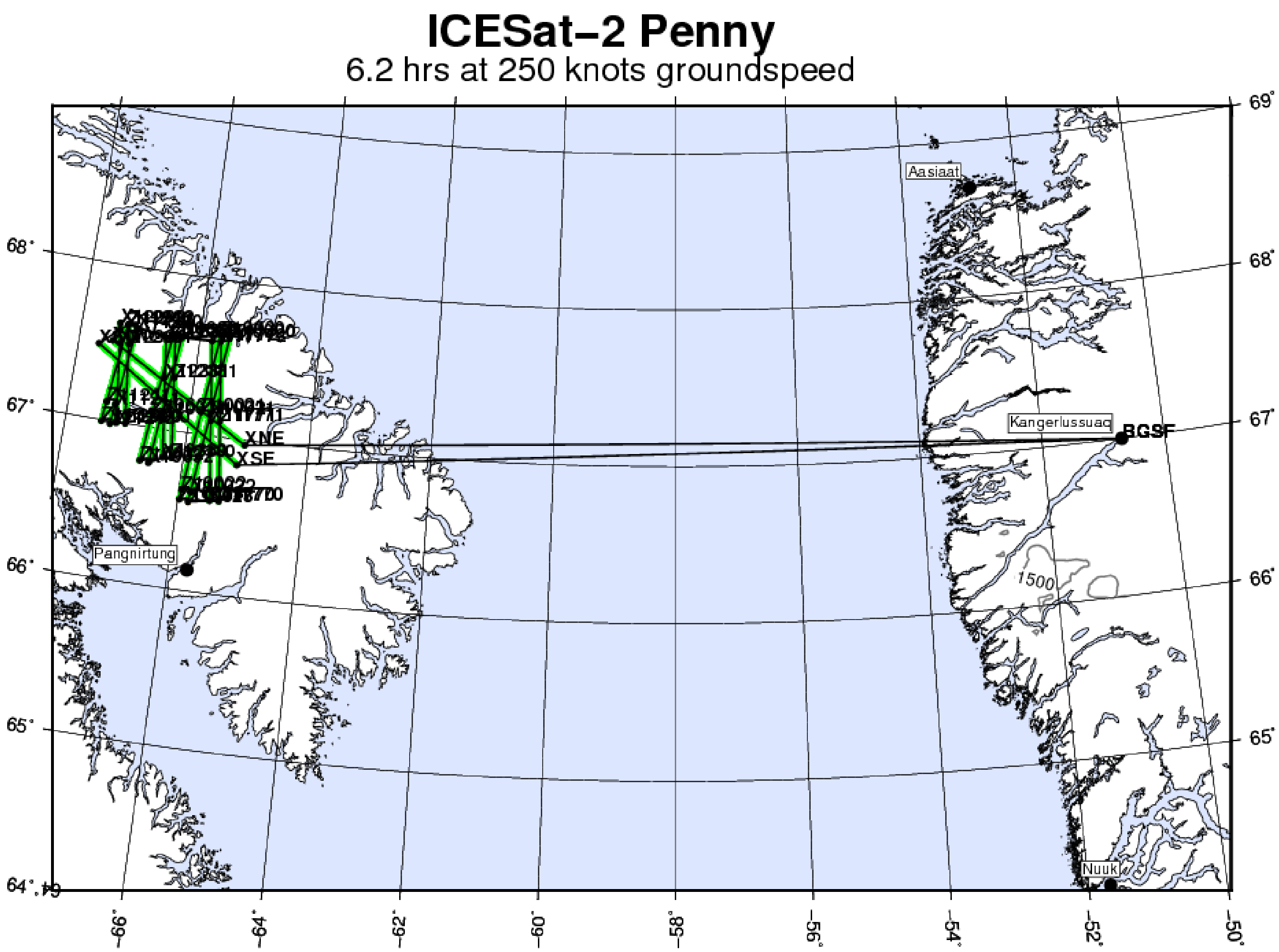
Flight Priority: medium
ICESat Track: none
Last Flown: 2018
Remaining Design Issues: none



Land Ice – ICESat-2 Penny / Kangerlussuaq

This is a new mission for 2019, designed to sample the left and right beam pairs of ICESat-2 over the Penny Ice Cap and nearby undulating bare rock. The intention is to validate the geolocation of ICESat-2 footprints. The pattern of ICESat-2 ground tracks is nearly repeated, targeting the left beam pair on one pass and the right pair on the other.

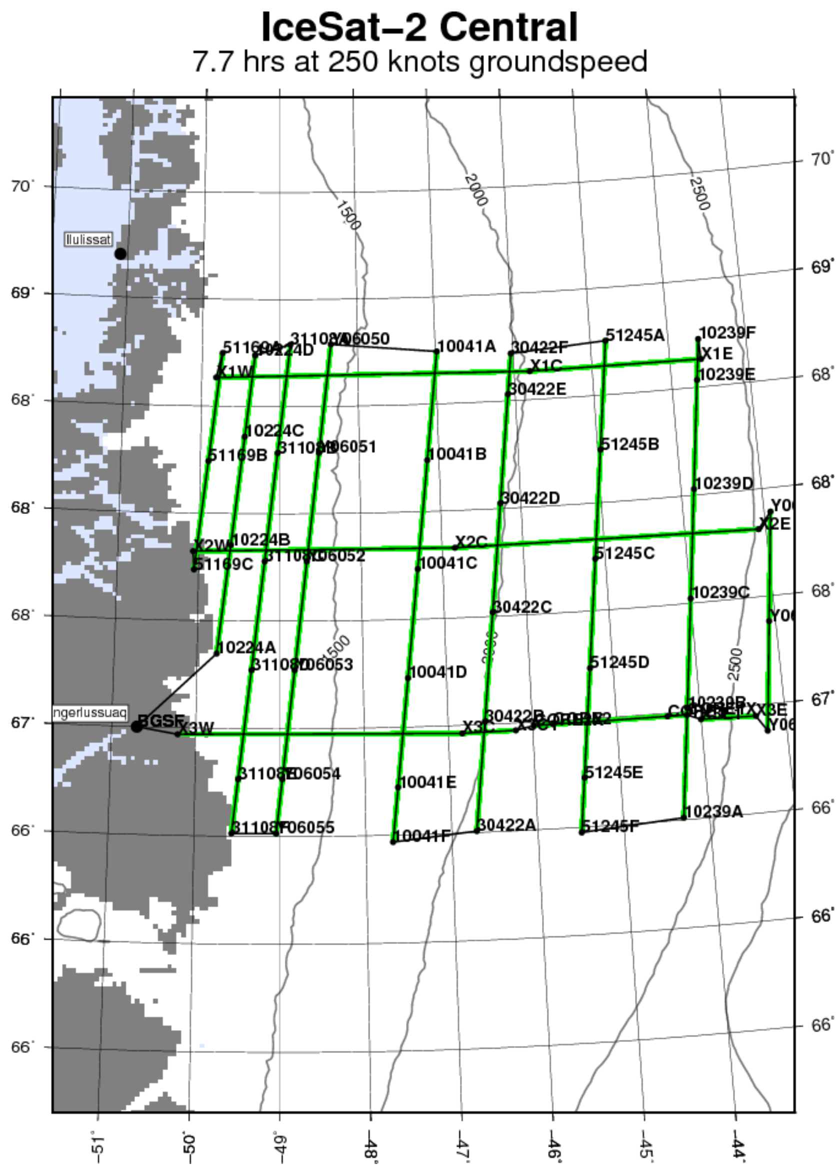
Flight Priority: high
ICESat-2 Tracks: X1299,Z1299,X1124,Z1124,X1238,Z1238,X1063,Z1063,X1177,Z1177,X1002, Z1002
Last Flown: new flight
Remaining Design Issues: none



Land Ice – IceSat-2 Central / Kangerlussuaq

This mission was designed to overfly planned IceSat-2 ground tracks over a wide range of ice regimes near Kangerlussuaq. We center some of the flightlines on each of three beam pairs (left, nadir and right) in turn, sampling three of each beam pair during this mission. The east-west crossing lines are designed to capture as many ascending/descending crossovers as possible.

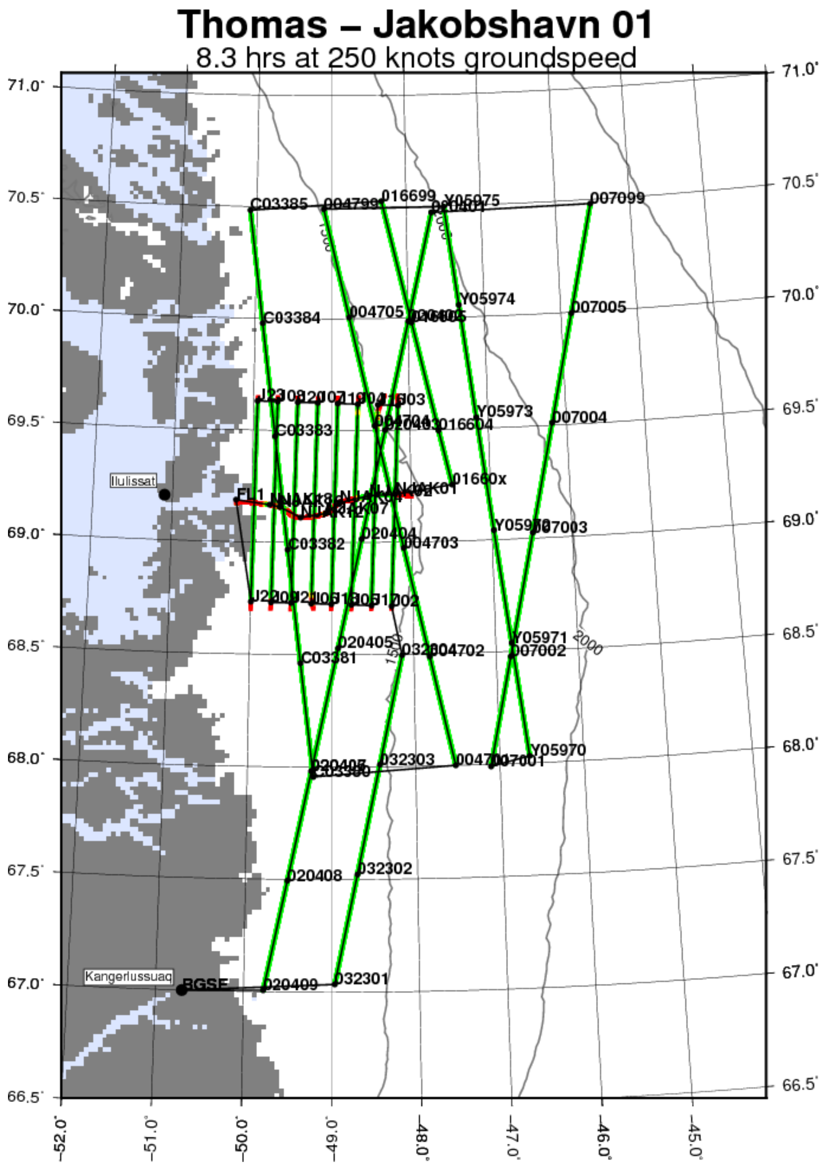
Flight Priority: high
IceSat-2 Track: 1169,1022,1047,0041,0422,1245,0239,0178
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Thomas-Jakobshavn 01 / Kangerlussuaq

This is a repeat of 2009, 2010, 2011, 2012, 2013 and 2014 IceBridge missions. Its purpose is to re-survey the highest-priority lines of the historical ATM 10-km Jakobshavn grid, the main flowline of Jakobshavn. It also extends that grid with a broader array of ICESat ground tracks over the larger Jakobshavn basin. Renamed in 2015 in honor of Robert H. Thomas.

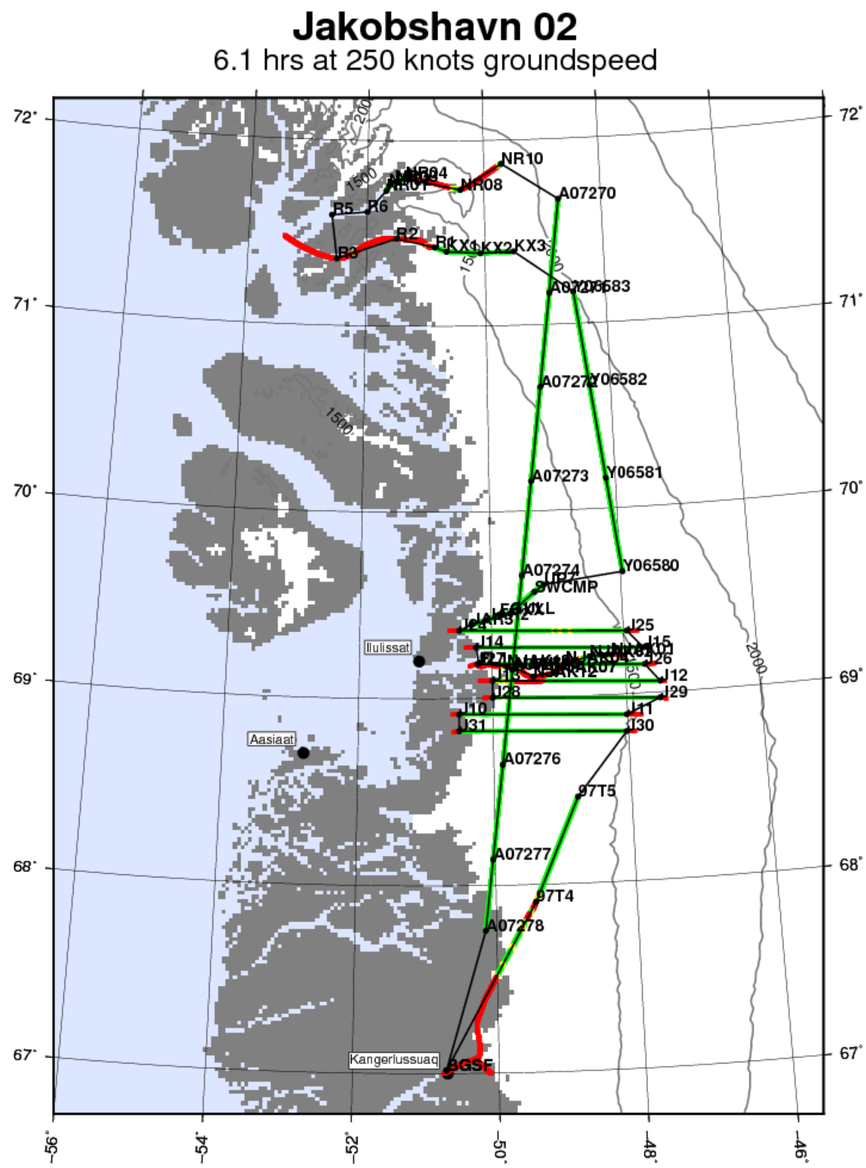
Flight Priority: high
ICESat-1 Tracks: 0323,0047,0285,0070,0204
ICESat-2 Tracks: C0338
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Jakobshavn 02 / Kangerlussuaq

This mission is a repeat of similar 2009, 2010, 2011, 2012, 2013 and 2014 OIB flights. The primary science objectives are to (a) complete the basic Jakobshavn grid, specifically the east-west lines, and (b) repeat longitudinal surveys of the Rink and Kangerdlugssup Glaciers. We also occupy a line connecting Swiss Camp and a pair of Eric Lutz-requested points nearby. Finally we fly the main Jakobshavn centerline twice, once at normal speed and altitude, and again as low and slow as possible, for MCoRDS radar assessment. We also include centerlines of Rink and Kangerdlugssup Glaciers, which can be eliminated if these glaciers were flown as part of the Jakobshavn-Eqip-Store flight.

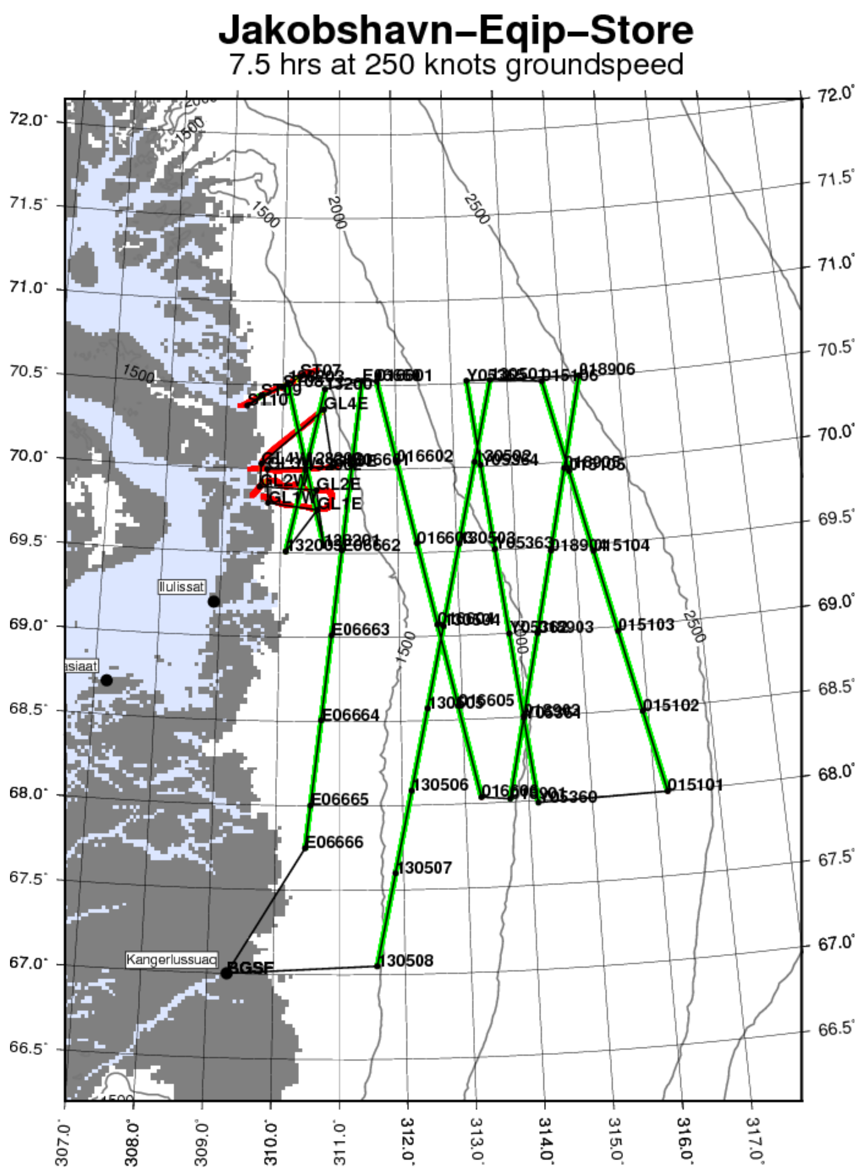
Flight Priority: medium
ICESat-2 Track: A0727
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Jakobshavn-Eqip-Store / Kangerlussuaq

This is a modified version of the 2011 Jakobshavn-Lake mission, whose main purpose it to extend the ICESat grid begun with Jakobshavn 01 farther upstream. We also densify the ICESat grid over the Eqip Sermia catchment area north of Jakobshavn, and we refly the centerlines of Eqip Sermia, Kangilerngata Sermia, Sermeq Kujalleq and Store Glaciers.

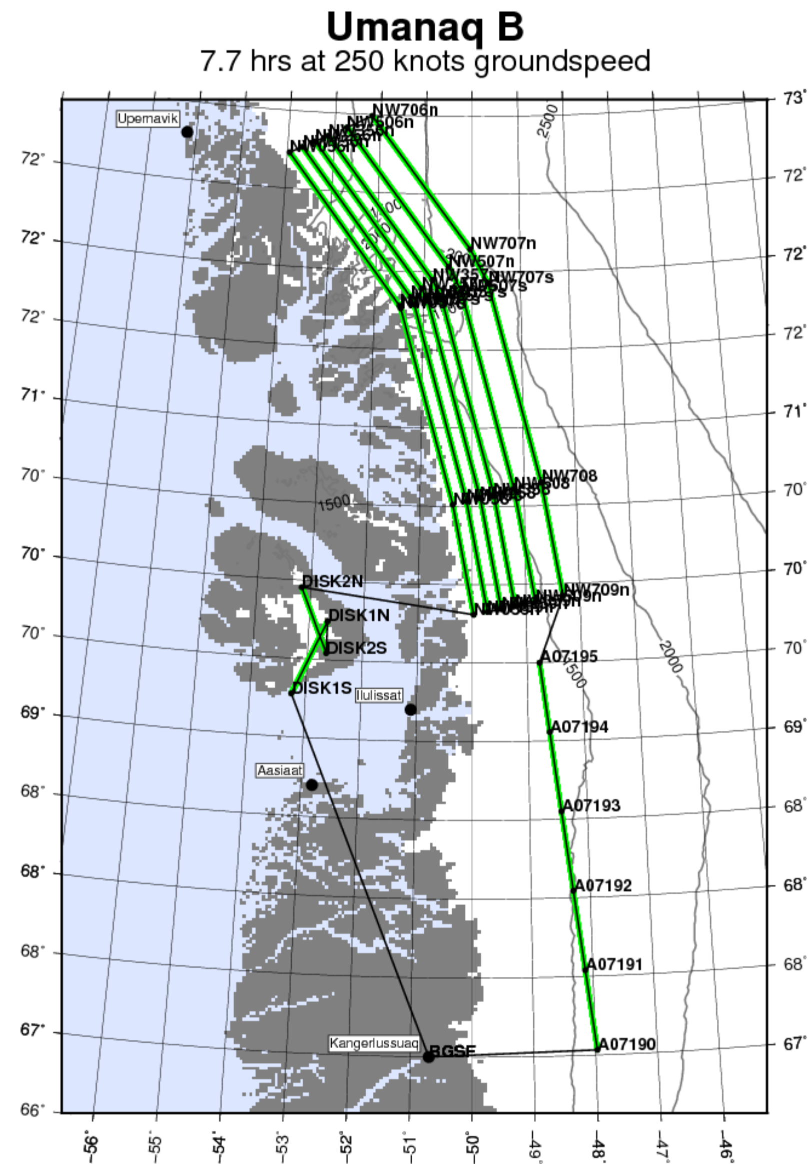
Flight Priority: high
ICESat-1 Tracks: 1320,1282,0166,0189,0151,1305
ICESat-2 Tracks: E0666,E0475
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Umanaq B / Kangerlussuaq

This mission is designed (along with Umanaq A) to refly the 2012 Umanaq coast-parallel grid with a pair of interlaced missions. This mission by itself reoccupies a grid spaced at 10 km near the coast, widening to 20 km upstream. The two flights together establish a grid at half this spacing. We also refly a pair of 2012 lines over the Disko Island ice cap.

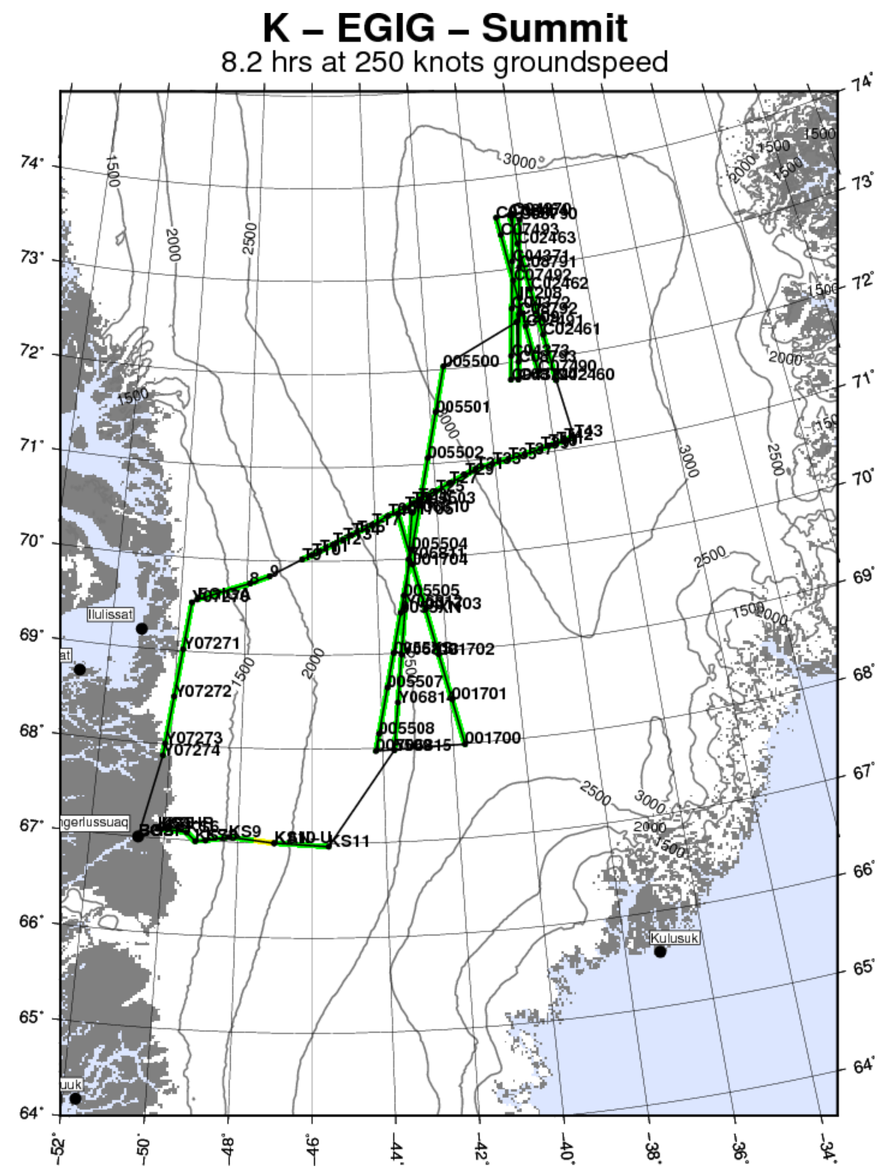
Flight Priority: medium
ICESat -2 Track: A0719
Last Flown: 2019
Remaining Issues: none



Land Ice – K-EGIG-Summit / Kangerlussuaq

This mission was designed to accomplish a number of high-priority tasks. First, we refly the van den Broeke "K-Transect" in the Russell Glacier catchment, consisting of several sites where comprehensive glaciological measurements are collected annually. We also fly the EGIG traverse line, which is expected to be occupied as part of the CryoVex effort in spring 2019. We overfly the IceSat-1 track 412 Summit calibration site. Finally we extend the coverage of the Jakobshavn basin upstream along IceSat-1 tracks, to capture continued inland progression of thinning there.

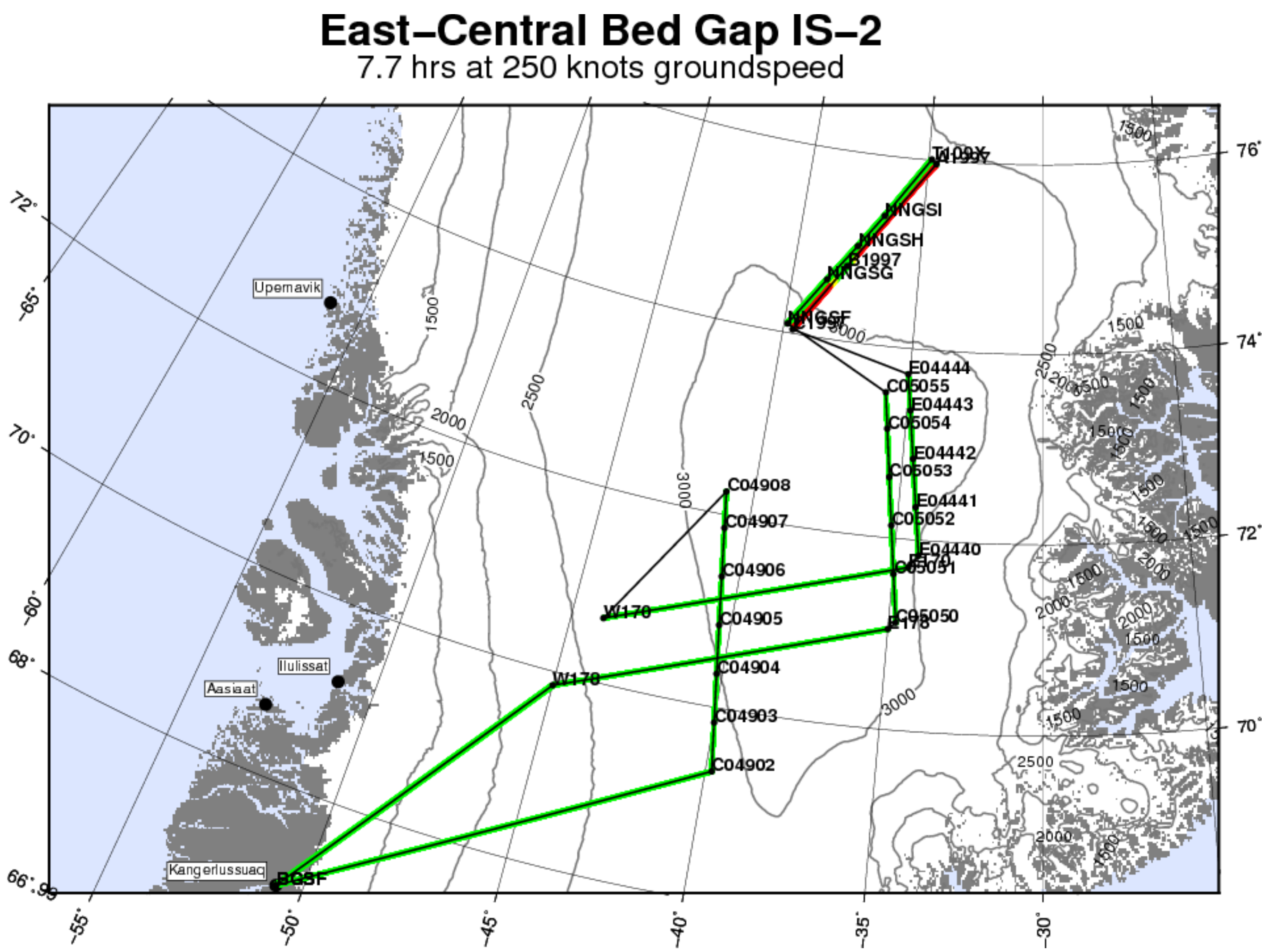
Flight Priority: high
Satellite Tracks: 0017,0055,0412,1320 (IS-1), C0795,C0879,C0437,C0749,C0246 (IS-2)
Last Flown: 2019
Remaining Design Issues: none



Land Ice – East-Central Bed Gap IS-2 / Kangerlussuaq

This mission was designed with two goals in mind. First, it (along with the Thule-based West-Central Bed Gap 01 flight) are designed to address the largest gaps in knowledge of the bedrock geometry still existing in Greenland. This flight does so along carefully-selected segments of two master grid lines and three low-latency ICESat-2 tracks. In addition, this flight addresses the onset region of the Northeast Greenland Ice Stream with a repeat of a 1997 line on its eastern margin and a new line along its centerline.

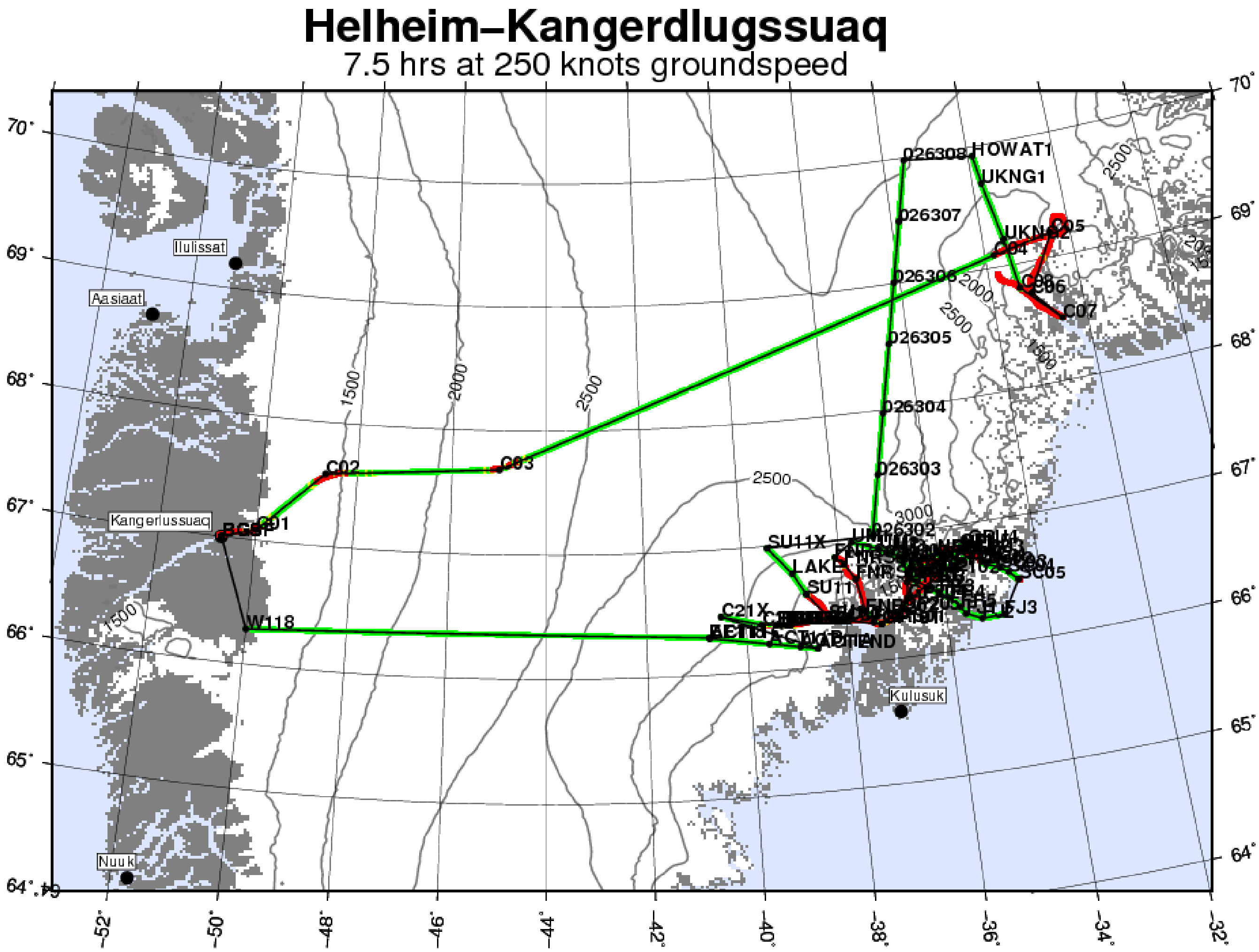
Flight Priority: low
ICESat Track: C0490,C0505,E0444
Last Flown: 2019
Remaining Design Issues: none



Land Ice – Helheim-Kangerdlugssuaq / Kangerlussuaq

This is a repeat mission, and is very similar to missions flown in 2010, 2011, 2012 and 2013. It captures centerline surveys of the two main branches of Helheim, of Kangerdlugssuaq, Fenris and of several branches of Midgard glaciers. For 2018 we extend the main (northwest) and west centerlines of Helheim Glacier to above the 2000m contour line. Note that this mission was NOT flown in spring 2019.

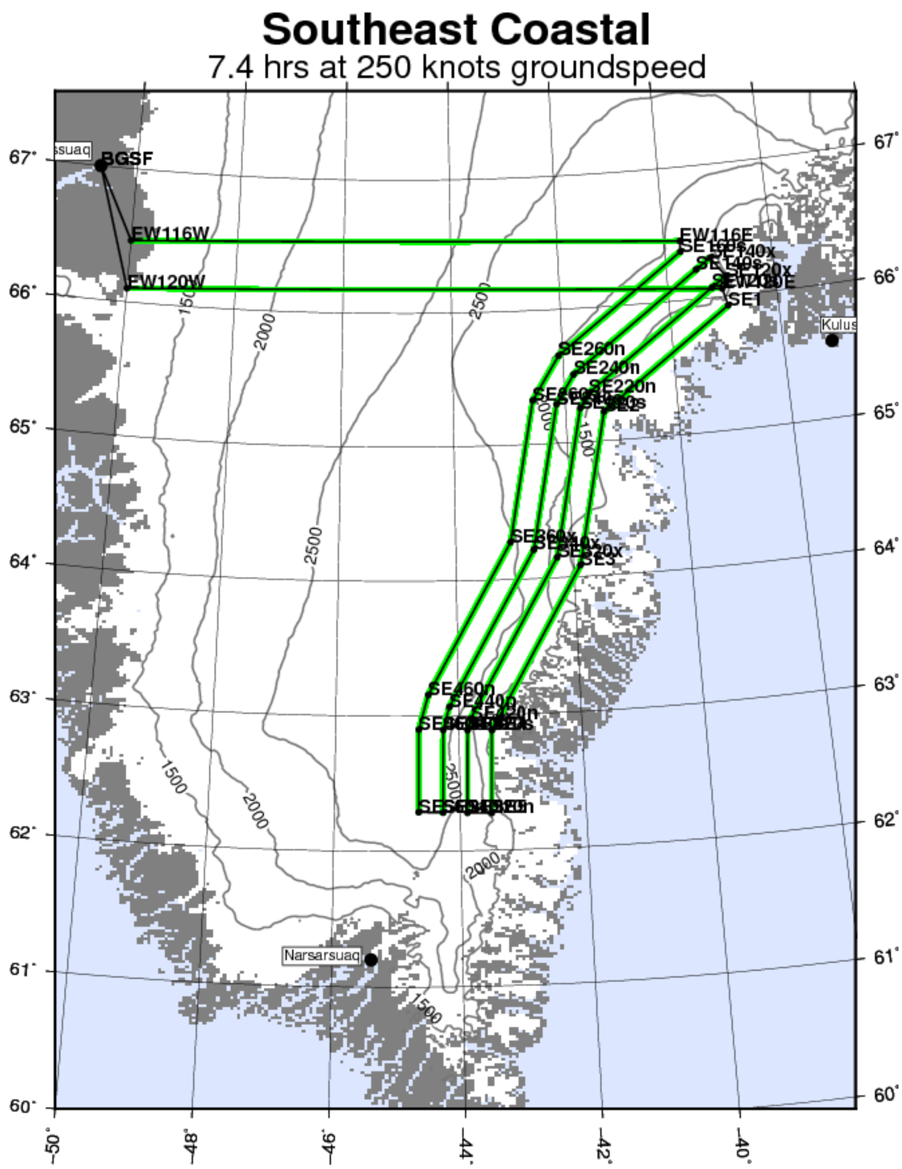
Flight Priority: medium
ICESat Track: 0263
Last Flown: 2018
Remaining Design Issues: none



Land Ice – Southeast Coastal / Kangerlussuaq

This mission reflies a 20-km coast-parallel grid along the southeast Greenland coast, enabling direct measurement of dh/dt in the catchment areas of the many major glaciers in the area across a range of surface elevations. Note that this mission was NOT flown in spring 2019.

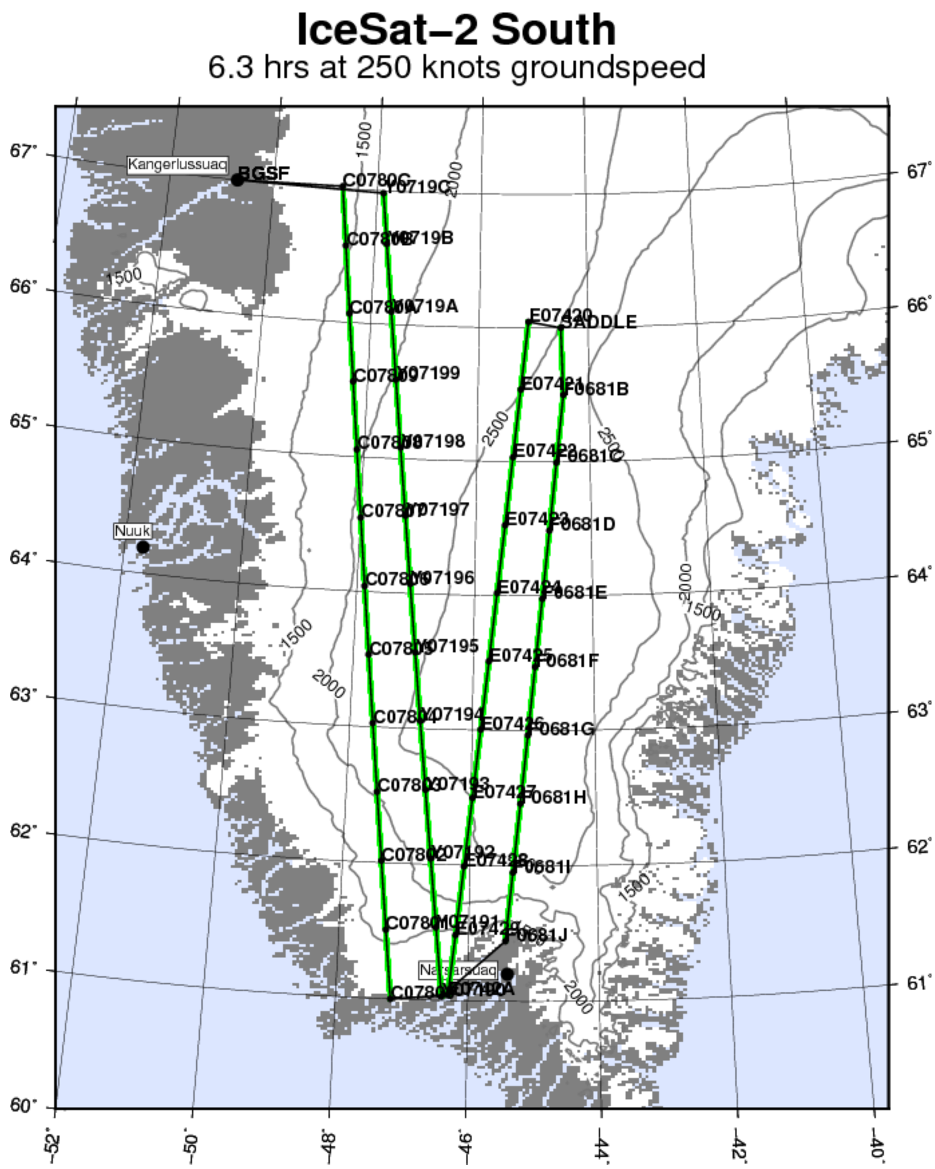
Flight Priority: medium
ICESat Track: none
Last Flown: 2018
Remaining Design Issues: none



Land Ice – IceSat-2 South / Kangerlussuaq

This mission is designed along IceSat-2 ground tracks to fill the gap between the southeastern and southwestern suites of missions. We sample a total of six IceSat-2 orbits, mixing left, nadir, and right beam pair overflights. We also overfly a firn compaction study site at point Saddle.

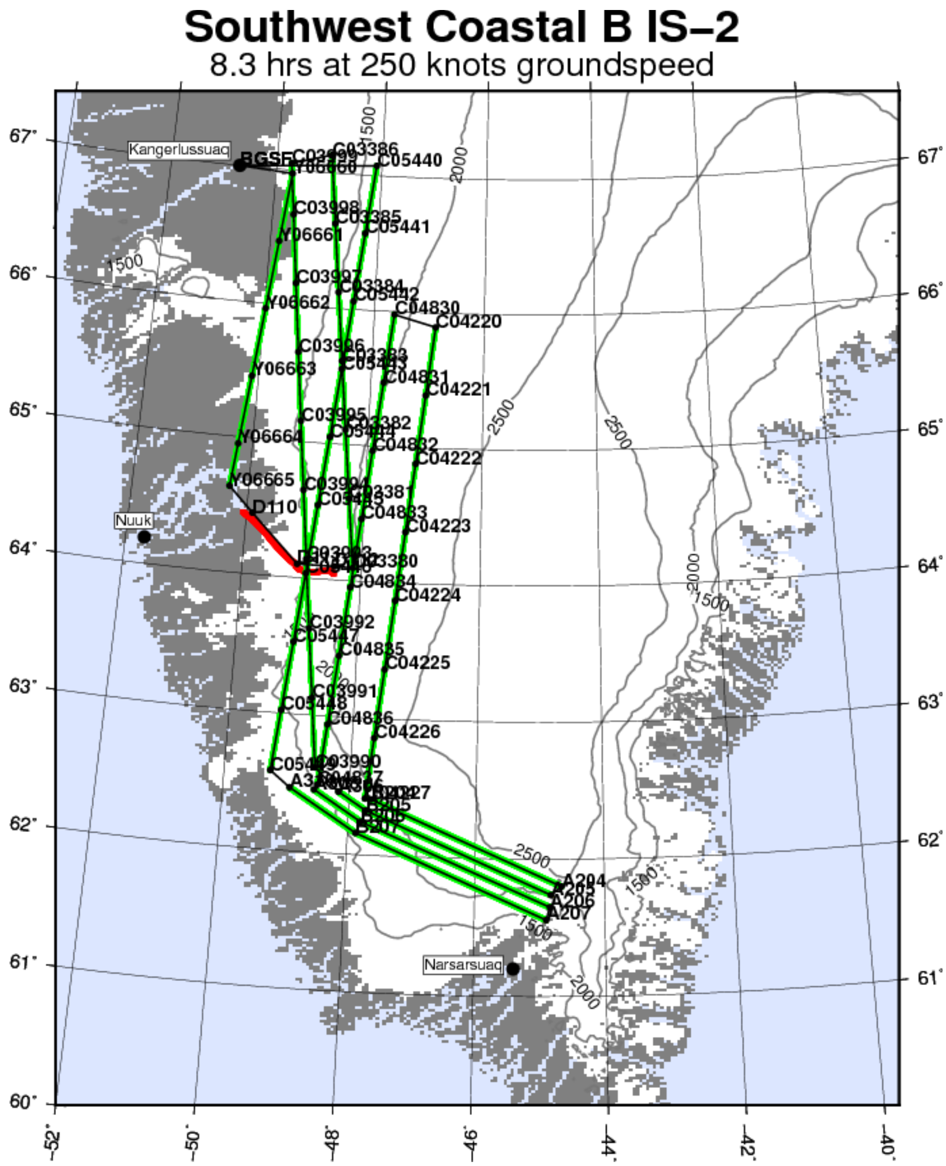
Flight Priority: medium
ICESat-2 Track: C0780,E0742,F0681,A0719,B0658,D1039
Last Flown: 2019
Remaining Design Issues: replace western lines with low-latency IS-2 tracks



Land Ice – Southwest Coastal B IS-2 / Kangerlussuaq

This mission is one of two (with Southwest Coastal A) designed to mirror the southeastern coast-parallel coverage in the southwest, along 2011 LVIS flight lines. This particular flight captures the higher-altitude portion of this part of the ice sheet. We also fly the Kangiata Nunaata Sermia glacier.

Flight Priority: high
ICESat-2 Tracks: C0338,C0399,C0422,C0544,C0460,C0483
Last Flown: 2019
Remaining Design Issues: replace any lines with low-latency IS-2 tracks



Appendix A: Status of Community Flight Requests

Requests for flight line modifications from the OIB science team are incorporated into the flight lines, in an interactive manner with the team through telecons and the planning meeting. The status of requests from researchers without an institutional connection to OIB, which are by nature less interactive, are summarized below. The color code below is as follows: green=request explicitly addressed in flight plans, blue=request could not be addressed, red=request yet to be addressed

Appendix B: ICESat-2 Beam Patterns and OIB

The ICESat-2 ATLAS instrument emits 6 individual laser beams in a pattern fixed relative to the structure of the spacecraft. We refer to these 6 beams, when expressed in the frame of reference of the spacecraft itself (and NOT their positions on the earth's surface), as the "engineering beams". The six beams are not identical – they are divided into "strong" and "weak" beams, three of each. Additionally two of the three "strong" beams are also known as TEP (Transmit Echo Path) beams, meaning that IceSat-2 records something similar to their start pulse waveforms. We also have a database known as the "reference ground track", which are in fact the geodetic coordinates of the six beams along the surface of the earth. These are labeled with numbers 1, 2 and 3 designating, respectively, the left, center and right beam pairs, and by L and R within each pair designating the left or right beam, Thus the right beam of the center (nadir) beam pair is 2R, and the left beam of the right beam pair is 3L. For this discussion, the terms "left" and "right" are from the perspective of a person facing the direction of travel of the spacecraft.

Since the yaw attitude of the spacecraft is not fixed, the relationship between the six engineering beams and the six reference ground tracks are also not fixed, and we seek to understand how to map the engineering beams to the reference ground tracks in a simple and reliable manner. This is necessary because the 6 engineering beams are not identical to each other.

The six engineering beams are arranged in three pairs, with two near nadir, two at spacecraft left, and two at spacecraft right. The beams are labeled numerically 1-6. Each pair has one strong and one weak beam. The strong beams are the odd-numbered beams 1, 3 and 5, while the weak beams are the even-numbered beams 2, 4 and 6. The TEP beams are 1 and 3. The beam pairs are separated by ~3.3 km across-track, and the two beams in each pair are separated by ~90 m. But depending on the yaw attitude of the spacecraft, the relative locations on the ground of the strong and weak beams, and two TEP beams, varies.

For the reference ground tracks, the six beam paths (1L,1R,2L,2R,3L and 3R) are invariant with spacecraft attitude. Beam 2L, for instance, is always the left beam of the center beam pair, though beam 2L might correspond to different engineering beams depending on the spacecraft's yaw attitude. Figure B1 below depicts the reference ground track geometry for one ascending track near Summit Camp, Greenland.

For the purposes of ATM and OIB, we must identify reference ground tracks by single characters rather than the two-character 1L etc scheme, due to a number of different software limitations. So internally, we replace 1L with A, 1R with B, etc through 3R with F. For flight planning purposes, we also have three "virtual" reference ground tracks, X, Y and Z. Each corresponds to the centerline of a beam pair, with X for the left beam pair centerline, Y for the center pair, and Z for the right pair. This is in response to a recommendation from the OIB science team to fly the centerlines of the beam pairs in certain circumstances, rather than center the aircraft on specific individual beams. Figure B1 also shows the correspondence between the internal beam letters (A-F) in the reference ground track and the more generally-used two-character scheme.

For the summer 2019 Operation IceBridge deployment time frame, the yaw orientation is expected to switch from the "-X" to the "+X" orientation on or about 6 September. The exact time/orbit at which the transition will be made is undetermined at the time of this writing. Thus, mission planning details will have to take this change into account. It is likely that OIB's base of operations will change from

Thule to Kangerlussuaq within a few days of 6 September, which means that, for the most part, Thule-based missions can be designed around the “-X” orientation, while Kangerlussuaq-based mission can be designed with the “+X” orientation. There may be a small number of “orphan” missions, which may need to be adjusted depending on whether they are flown before or after the IS-2 yaw maneuver.

Tables B1 and B2 below show the mapping between engineering beams and reference ground track designations, for before and after the yaw transition, respectively. The two colors in the tables indicate that items highlighted in the same color remain in lockstep regardless of the spacecraft’s yaw attitude, while items in different colors change in their relation to each other when yaw orientation changes. For instance, ref track ID 2L always corresponds to internal ref track letter C, and engineering beam 3 is always a strong beam with TEP. But the laser occupying ref track 2L is not always strong beam #3.

Table B1. Beam mapping for -X orientation, prior to 6 Sept 2019.

Ref track ID	Ref track letter (OIB internal)	Engineering beam #	Beam type	TEP
1L	A	1	strong	yes
1R	B	2	weak	no
2L	C	3	strong	yes
2R	D	4	weak	no
3L	E	5	strong	no
3R	F	6	weak	no

Table B2. Beam mapping for +X orientation, after 6 Sept 2019.

Ref track ID	Ref track letter (OIB internal)	Engineering beam #	Beam type	TEP
1L	A	6	weak	no
1R	B	5	strong	no
2L	C	4	weak	no
2R	D	3	strong	yes
3L	E	2	weak	no
3R	F	1	strong	yes

Table B3, below, identifies the geometric meaning of the “virtual” reference track letters X, Y and Z, which are the centerlines of the respective beam pairs. These are created (internal to ATM/OIB) for flight planning purposes because of a recommendation from the OIB science team that, in some cases, we place the aircraft not over a specific beam but over the center of a given beam pair. This is usually intended to maximize our chances of covering both beams of a pair with the ATM wide scanner (~250 m in width).

Table B3. OIB's virtual reference ground tracks.

Virtual track letter (OIB internal)	**Corresponds to beam pair centerline**
X	Left / 1
Y	Center / 2
Z	Right / 3

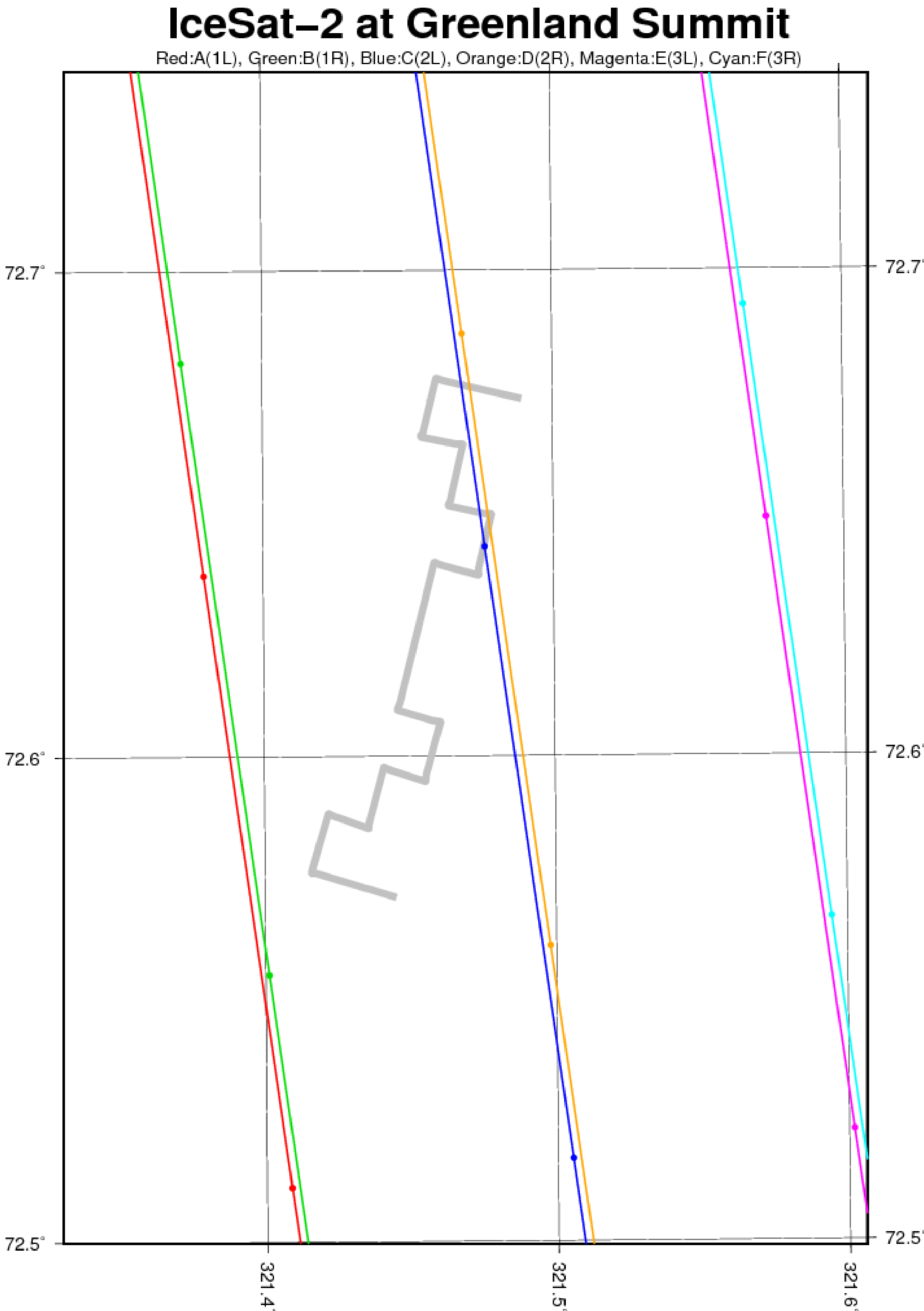


Figure B1. Ascending ICESat-2 reference ground tracks (ref orbit #0749) at Summit, Greenland.

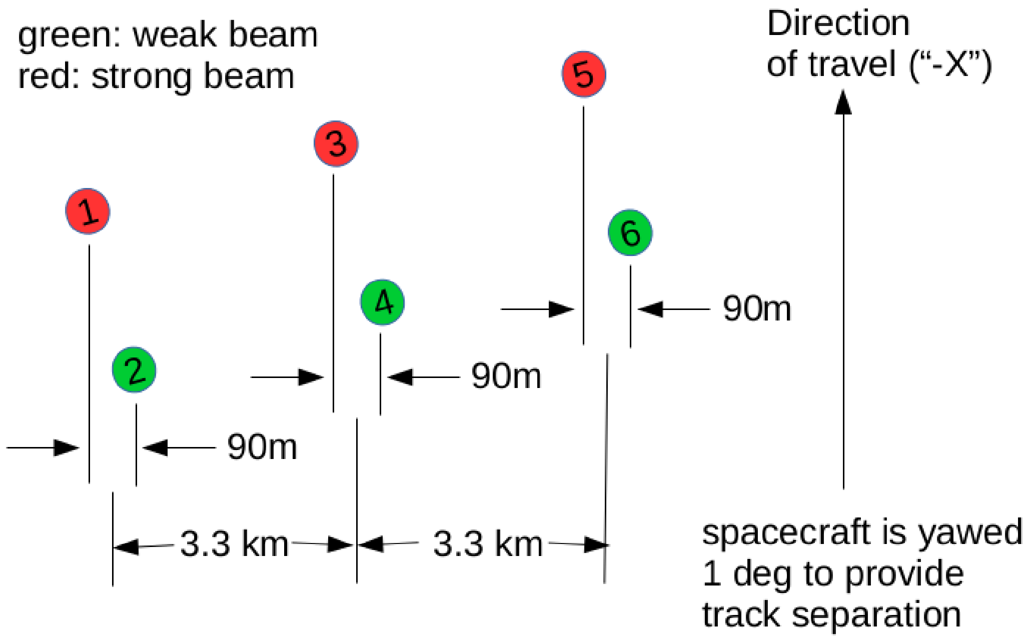


Figure B2. Spacecraft beam pattern for "-X" orientation.

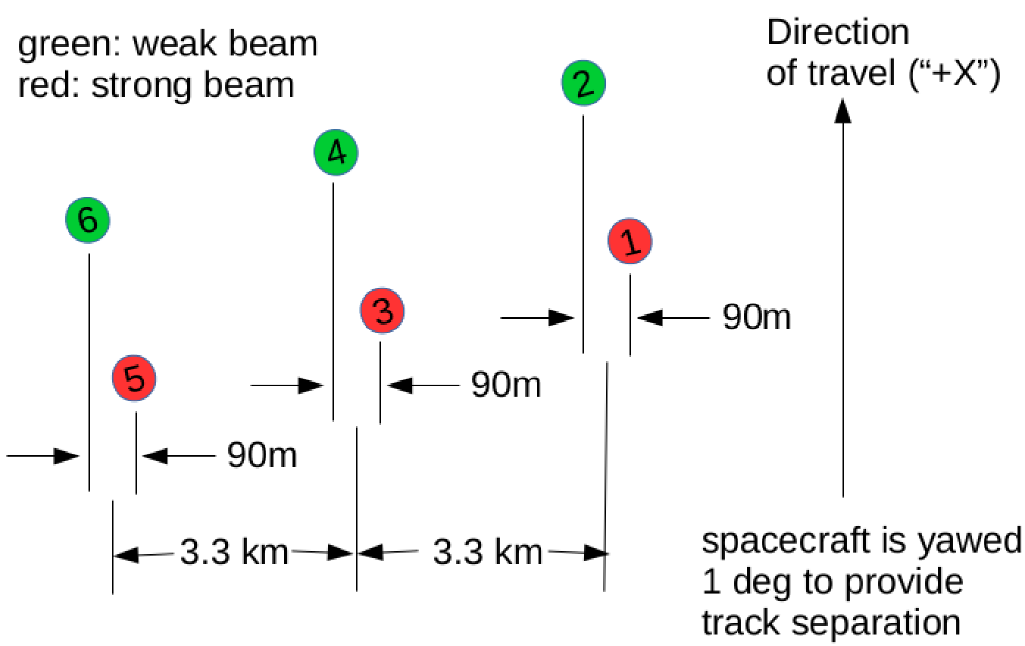


Figure B3. Spacecraft beam pattern for "+X" orientation.

Appendix C: Sea ice drift corrections

For 2018 and 2019, a requirement arose from the OIB science team to apply “drift corrections” to some of our planned flight paths. These corrections apply to all sea ice missions that include a low-latency ICESat-2 component.

The purpose of the corrections is to modify our flight paths, according to the time differences between the expected time of our aircraft’s arrival at each of our waypoints and the overflight time of the ICESat-2 spacecraft, and according to the expected drift velocity of the sea ice. At each waypoint, the drift correction yields a position offset which can be applied in real-time as we fly. The result is that we improve the chance that our aircraft and the spacecraft measure the same swath of sea ice within a few hours, even as the ice itself drifts according to winds and currents.

An important component of the drift correction arises from the surface winds. Since the G-V has real-time winds readily available to the flight crew and hence to the instrument team, we can use winds measured in-situ and in real time to inform the drift correction. Since we measure winds at altitude, while the surface winds are what is required, we will apply altitude-dependent scaling corrections to the wind speed as part of the drift correction algorithm.

Our plan for determining the drift corrections is as follows. When we initially enter the survey line, we will note the wind speed and direction at our altitude. If possible given visibility conditions and other factors, we will descend to as low as 500’ AGL and remain there for ~60 seconds to allow the air data measurements to stabilize, then note the wind speed and direction there, since we expect that winds at a lower altitude will better represent the surface winds than those measured at higher altitude. Regardless of the altitude used to measure the winds, we will then enter these measurements into a software tool which will determine a velocity vector, representing our best estimate of the current sea ice drift rate and direction. For each waypoint in the flight plan, the software tool will calculate the time difference between our arrival at that waypoint and the spacecraft’s arrival over the flight line, and use the drift correction velocity vector to calculate a position offset vector. These position corrections will then be applied to every remaining waypoint in the flight plan. We will repeat the wind measurement and drift correction procedure any time we note significant changes in the measured wind speed and/or direction.

The above applies to our “straight-line” IS-2 sea ice underflights, but we also plan to perform multiple “walking racetrack” style flights, with the multiple racetrack passes intended to broaden our composite swath for all passes. This should maximize our odds of capturing the same ice observed by ICESat-2 in the presence of errors in knowledge of drift and in knowledge of ICESat-2 pointing. For these racetrack flights, we conduct a single drift correction for all waypoints based on the time difference for the first pass around the pattern. The later passes, offset by several hundred meters, must retain a fixed amount of overlap with the earlier passes and thus should not be displaced differently.

The technical details of the drift correction algorithm are beyond the scope of this document, but are available upon request.

Appendix D: Design considerations for ICESat-2 sea ice missions

The IceBridge and ICESat-2 sea ice science team members have agreed that OIB should be prepared to fly as many as five dedicated ICESat-2 low-latency missions, in addition to the regular OIB sea ice survey missions. Three of these should be considered baseline-priority missions, and two as high-priority missions. We also hope to work low-latency IS-2 tracks into regular OIB missions as practical. But for the dedicated IS-2 missions, the design trade space is potentially enormous. Since these missions have to be designed close in time to the date on which they are to be flown (due to changing weather and orbital geometry and timing considerations), here we provide a “cookbook” for designing up to five of these missions.

For late summer 2019, low-latency ICESat-2 orbits are fairly well-placed for operations from Thule during normal airport opening hours. The best available ground tracks, based on their timing, will be descending ones, in the Lincoln Sea and points east. The suitable RGTs occur in the afternoon hours.

Three of the missions will be “walking-racetrack” style flights, intended to obtain very broad coverage over TEP beams A (“1L” to the IS-2 community) and C (“2L”). We place a single ~200 km pass over a drift-corrected, low-latency beam A and beam C flown in opposite directions (thus the “racetrack” analogy), then “walk” that racetrack pattern in a direction perpendicular to the ground track so that successive passes are offset to one or each side, depending on wind. The degree of offset should yield overlap of adjacent ATM wide-scan (T6) swaths of 15%. The racetracks should be flown at an altitude of 1000m, yielding a T6 swath of 500m and an overlap of 75m. Therefore the offset between adjacent flight lines should be 425m. We will perform a single discrete drift correction, using modeled surface winds obtained prior to takeoff, and calculated for the time elapsed between the spacecraft’s passage overhead and the time of our aircraft’s arrival on-site. Three of the five IS-2 dedicated sea ice flights should be these racetrack-style flights, with one placed around 100 km from the coast of the Canadian Arctic Archipelago, another placed several hundred km away from the coast, and a third roughly halfway between.

The racetrack pattern depends on winds. If the cross-track (relative to the IS-2 reference ground track) wind component is less than 3 knots, we drift-correct the A and C ground tracks according to modeled winds obtained prior to takeoff and our expected arrival time, and then offset the racetrack pattern 425m to the east, and then 425m to the west, for three circuits. If the cross-track wind component is greater than 3 knots and westerly, we drift-correct as above, then we further offset the reference tracks 50m west (upwind), offset the next pattern 425m to the east, and the third 850m to the east (walking the pattern downwind with time). If the winds are easterly and >3 knots cross-track, we do the reverse of the above. To account for differences in distance to and from Thule, we simply adjust the length of the racetrack legs accordingly.

Appendix E: WorldView / ICESat-2/ OIB coordination

The OIB science team (and others) requested that OIB data collection over ICESat-2 lines, on Arctic sea ice, be coordinated with WorldView satellite imagery collection as well. This effort is complicated by the fact that, for OIB, the IS-2 underflight lines are planned just a few days prior to the flight. This schedule is driven primarily by uncertainty in weather forecasts – we plan the underflights only when we believe that we have a reasonable chance of actually executing them. In practice, this means that we most often plan IS-2 underflights 1-2 days prior.

Given that, our plan for accomplishing the WorldView coordination is as follows. On a given day of the OIB Arctic campaign when sea ice flights are possible (probably between 19 August and 6 September 2019), we will consult weather forecast models and IS-2 orbit predictions, determining if any suitable coordinated sea ice underflights are likely to be successful two days hence (clear skies for both aircraft and spacecraft to see the surface). Between 1 and 3 OIB flight plans for that day will be generated, incorporating the low-latency IS-2 tracks. These flight plans, or their most relevant portions, will be sent via email to our WorldView targeting contacts (Steven Hak, jhak@usgs.gov). Since we will be in-flight from roughly 1100 to 1900 UTC on these days, we will be able to send them only after we land, giving our WorldView contact(s) on the order of 36 hours to process the targeting requests.